SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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Public Relations, Plant Dedications

OCTOBER 1959—VOL. 31, No. 10

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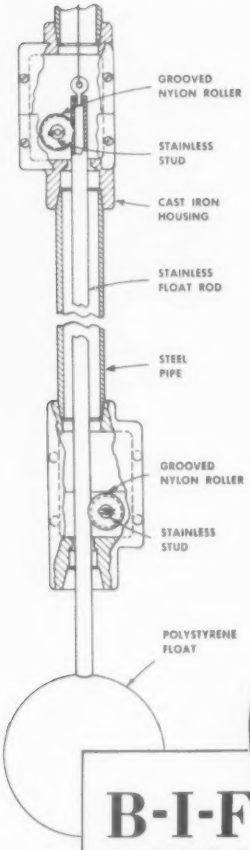

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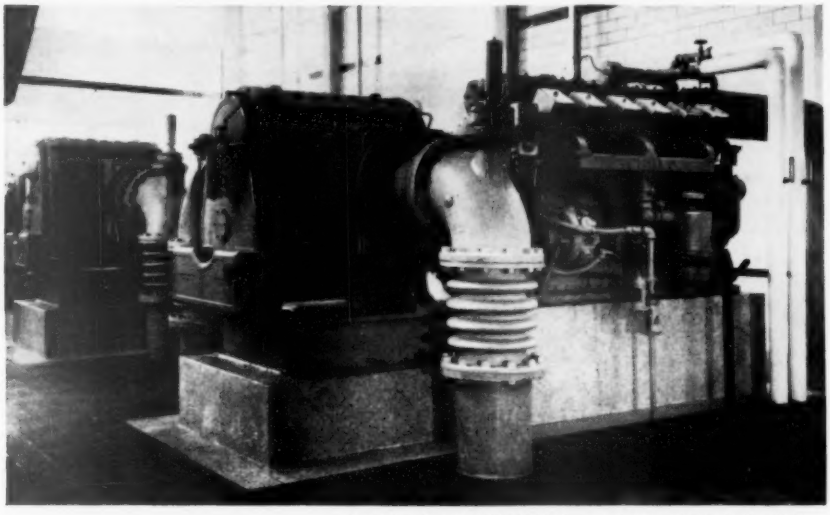

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 **October 1959** **Number 10**

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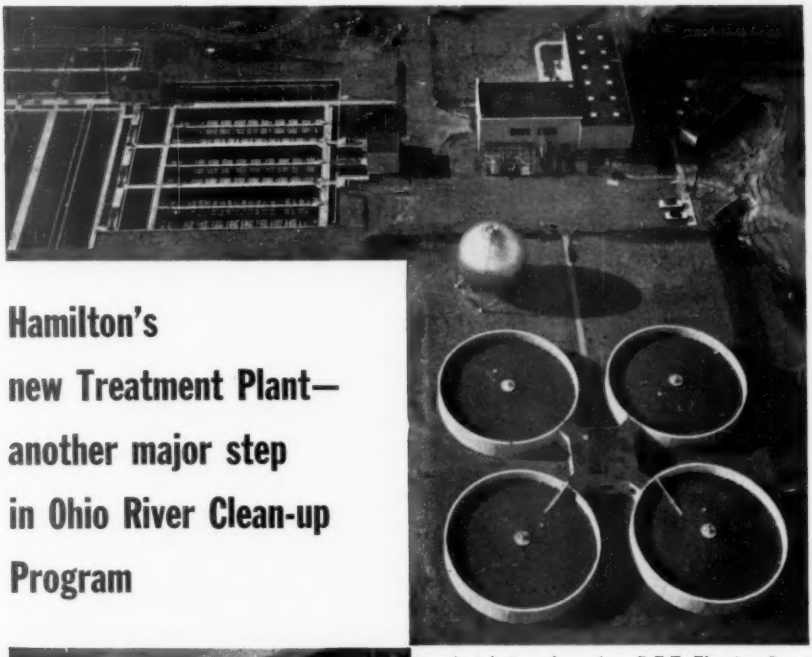
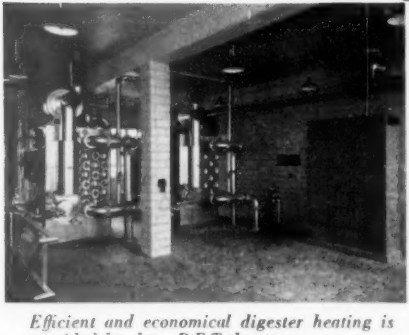


Hamilton's new Treatment Plant— another major step in Ohio River Clean-up Program

Aerial view shows four P.F.T. Floating Cover Digesters



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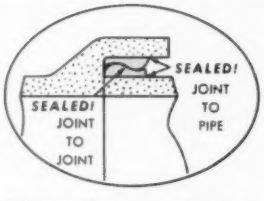

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W. Va. Sewage and Industrial Wastes Assn.	Chancellor Hotel Parkersburg, W. Va.	Oct. 29–30, 1959
Pacific Northwest Sewage and Industrial Wastes Assn.	Hotel Tioga Coos Bay, Ore.	Oct. 29–31, 1959
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South Carolina Water and Sewage Works Assn.	Jefferson Hotel, Columbia, S. C.	Nov. 6, 1959
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Oklahoma Water, Sewage and Industrial Wastes Conf.	Student Union, Okla. State Univ. Stillwater, Okla.	Nov. 16–20, 1959
Indiana Sewage and Industrial Wastes Assn.	Washington Hotel, Indianapolis, Ind.	Nov. 18–19, 1959
New York Sewage and Industrial Wastes Assn.	Park Sheraton Hotel New York, N. Y.	Jan. 20–22, 1960

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Statler Hilton Hotel, Dallas, Texas

Technical Meetings and Exhibits—Dallas Memorial Auditorium
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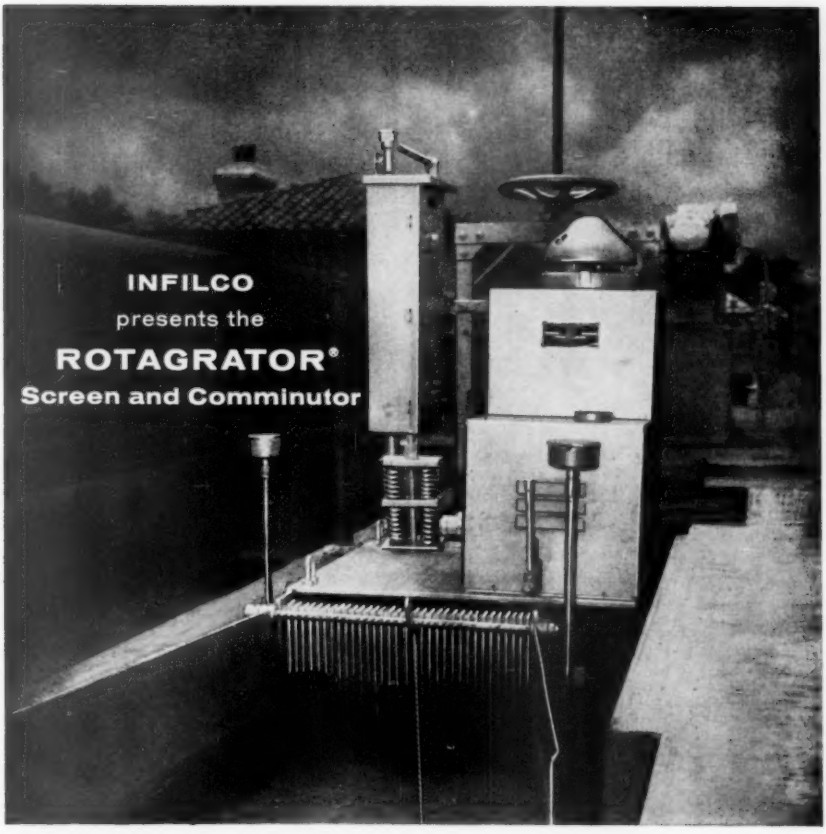

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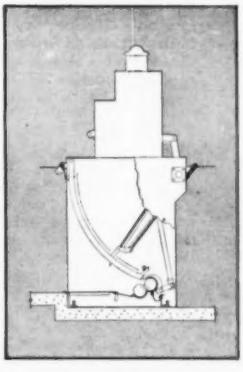

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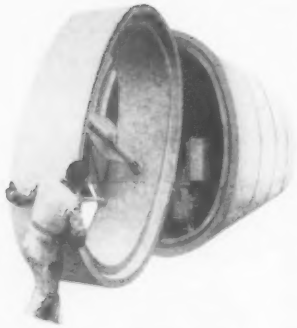

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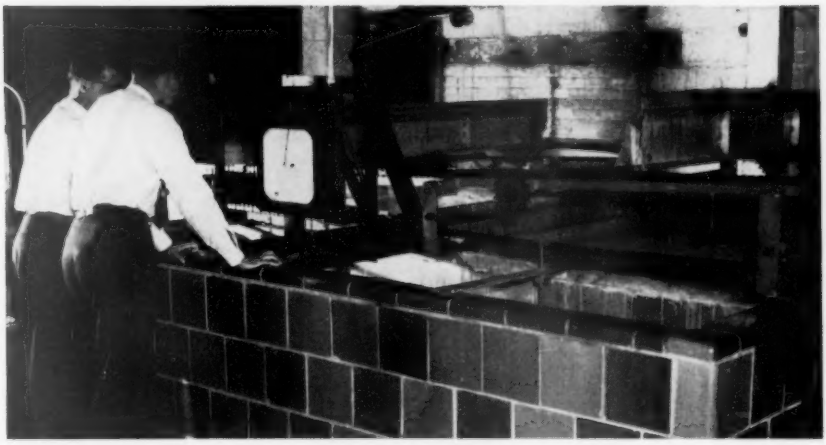


Checking clarified effluent of the Permutit Colloidair Separator at the Homasote Company

How to side-step a public health hazard . . . and step into big new savings

Maybe you have a problem similar to the one that confronted the Homasote Company, Trenton, N. J.

They make high-density wood fiber insulation board. The process *could* create a waste disposal problem and impair the company's good community relations.

The answer found by Homasote turned out to be more than just a waste treatment system. It is also a valuable way to save money, through reclaimed product and water.

The Permutit Colloidair Separator is behind this accomplishment.

Saves product. White water feeds into the Colloidair, where a "bubbling-out" process raises the fibers to the surface. These fibers are scraped off and reclaimed.

Saves water. No water is wasted in this closed-circuit operation. Colloidair clarifies it for Homasote's re-use in pump glands, stuffing box seals, and for general cleanup.

Saves heat. The reclaimed water holds most of its heat during the clarifying process. This saves the expense of reheating for re-use.

Easy to use. Colloidair works almost by itself. The operator does little more than periodically charge chemical tanks.

Homasote is getting these benefits today . . . when would YOU like to start?

We will be glad to run lab and/or pilot plant tests to show just what the Permutit Colloidair Separator can do with your white waters and/or waste waters.

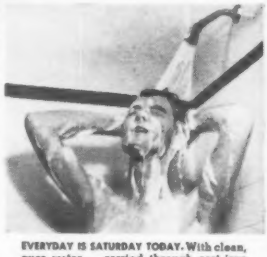
Save your public relations . . . and your money. Get more information on Colloidair by writing our Permutit Division, Dept. SI-109, 50 West 44th Street, New York 36, New York.

*FLUIDICS is a new Pfaudler Permutit program that provides a modern, imaginative approach for handling and processing liquids and gases more profitably.

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes

A BATH WAS AN OCCASION in Grandfather's day. Setting up the tub, heating bucketfuls of water was a chore even the fussiest usually confined to one day a week—Saturday night.



EVERYDAY IS SATURDAY TODAY. With clean, pure water . . . carried through cast iron pipe . . . the shower or bath today is an accepted part of American living.

U.S. cast iron PIPE

FOR WATER, SEWERAGE AND

U. S. PIPE AND FOUNDRY COMPANY

but better than ever today!

Mine-to-main control assures
U. S. Pipe quality in service

Water, harnessed and put to work, is the firmest base on which a community can build.

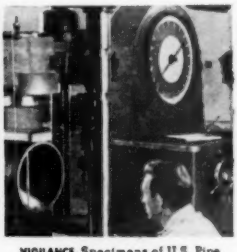
Water officials are doing an outstanding job keeping the nation's water pitcher filled. Cast iron pipe is their most dependable ally.

To furnish that dependability . . . in every detail . . . U. S. Pipe controls production every step of the way. From mine to final shipping U. S. cast iron pipe is subjected to intensive quality checks. . . checks to provide long life, efficiency, trouble-free service.

Quality is built into U. S. cast iron pipe.

CLEANING ORE. U. S. Pipe ore cleaning plant at a mine where ore is crushed and passed through separators to float off impurities.

MOLTEN IRON in a measured amount is poured into a machine ladle, preparatory to the start of the centrifugal casting cycle.



VIGILANCE. Specimens of U.S. Pipe are periodically subjected to a ring crushing test in a 200,000 pound universal testing machine.

INDUSTRIAL SERVICE CAST IRON

Birmingham 2, Ala. *A wholly integrated producer from mines and blast furnaces to finished pipe.*

Weir plates of Everdur control water flow in Toronto's new Humber plant

These corrosion-resistant Everdur weir plates will handle *50 million gallons* of water every day at the new Humber sewage treatment plant.

Easy fabrication. Everdur weir plates are being joined by arc welding prior to installation.

EVERDUR RESISTS CORROSION. Installations of Everdur sewage-treatment and waterworks equipment in the United States have been in service without replacement for 30 years and longer.

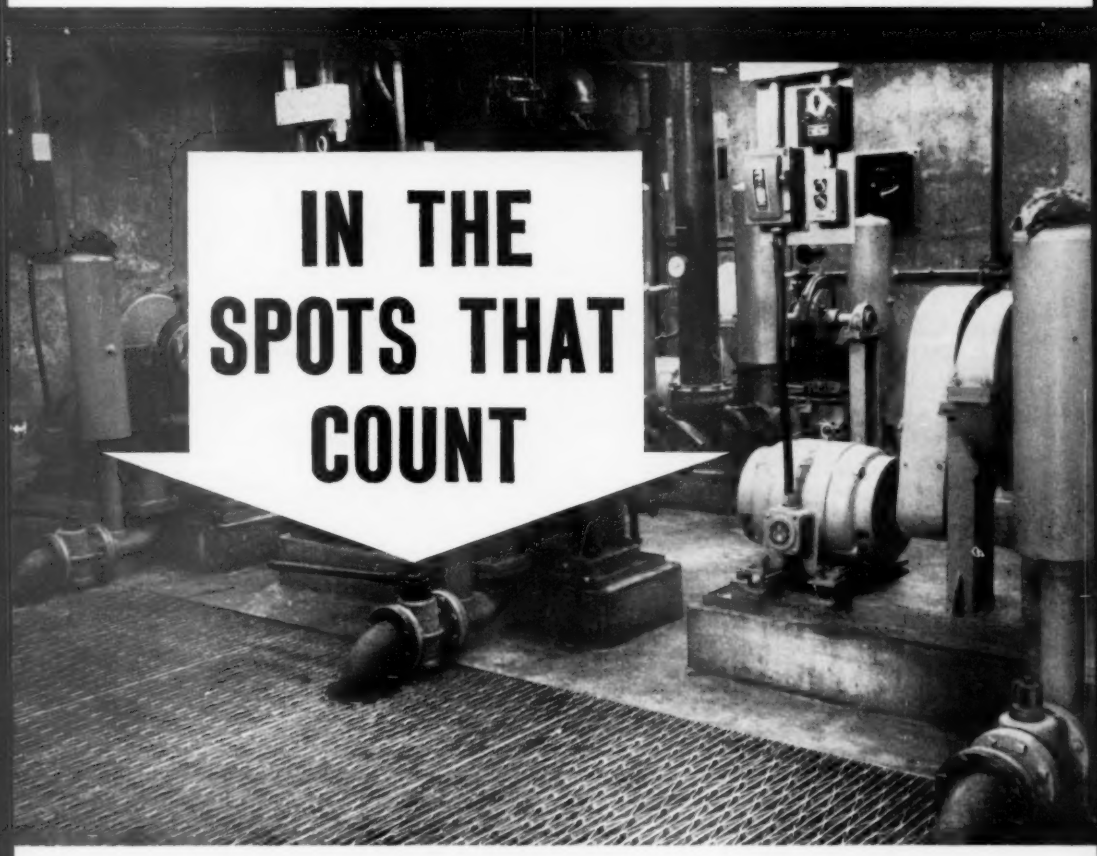
EVERDUR IS TOUGH. Everdur, Anaconda's group of copper-silicon alloys, also possesses high physical strength and resistance to wear and abrasion—so that wrought equipment can be designed with lighter weight.

EVERDUR IS READILY FABRICATED. Everdur alloys are available for hot or cold working, welding, free machining, forging and casting—and can be supplied in plates, sheets, rods, bars, wire, tubes, electrical conduit, and casting ingots.

WRITE FOR PUBLICATION E-11—or for assistance from the Technical Department in selecting the correct material for your equipment. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5996

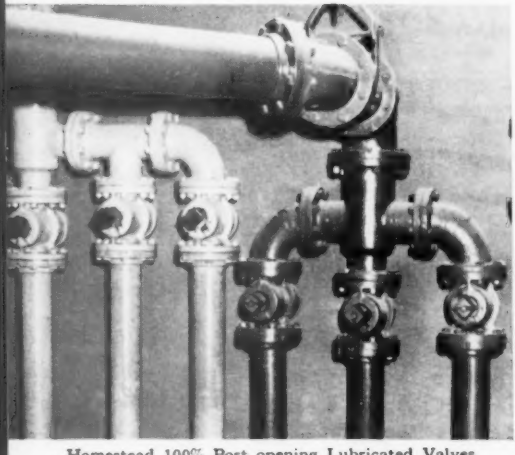
EVERDUR® Anaconda's Family of Copper-Silicon Alloys
MADE BY THE AMERICAN BRASS COMPANY

STRONG • WELDABLE • WORKABLE • CORROSION-RESISTANT



IN THE SPOTS THAT COUNT

Cedar Rapids Sewage Plant prefers Homestead 100% Port Opening Valves



Homestead 100% Port opening Lubricated Valves controlling supernatant, sludge and gas in Cedar Rapids Sewage Plant.

In the transport of sludge and grease from settling basins, full pipe area lines are essential to long pump life. That's why Howard R. Green Company, Engineers, specified 95-4", 15-6", and 9-8" Homestead Lubricated Plug Valves in this Iowa sewage treatment plant. Homestead's 100% pipe area design guarantees full flow—no restrictions to put a strain on pumps and motors.

Add positive lubrication and sealing, Homestead's leakproof no-stick design, plus minimum maintenance, and you'll know why Superintendent William J. Meaney says, "I'm fully satisfied with Homestead Valves on our lines."

Mail coupon today for Reference Books 39-1 and 1A—a complete library of Homestead Lubricated Plug Valves and their uses.

Please send me complete data on Homestead Lubricated Plug Valves and their suggested uses.

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Company.....

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Eimco-Process Equipment Can be Engineered to Meet the Needs of Any Community . . .

All over the United States, municipalities are finding it profitable to utilize, fully, today's modern cost-cutting equipment for sewage, industrial wastes and water treatment

That's why so many forward-looking communities from coast to coast have installed Eimco-Process equipment.

Operators of these plants have found that Eimco-Process equipment for gravity and flotation separation combines high efficiency, based on scientific design, and heavy-duty construction They get years of dependable performance, and many low maintenance advantages that result in reduced costs

The Eimco-Process representative in your area is a trained application engineer. He will be glad to work with your engineers or consultants on your specific problems. You can be sure that the equipment he recommends will be as well-suited to your job as careful planning and skillful engineering can make it

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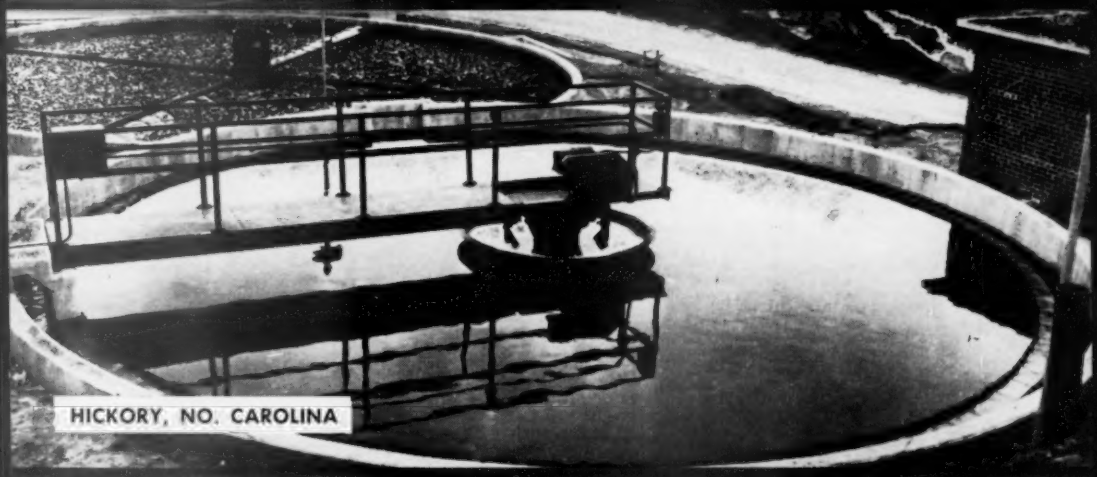
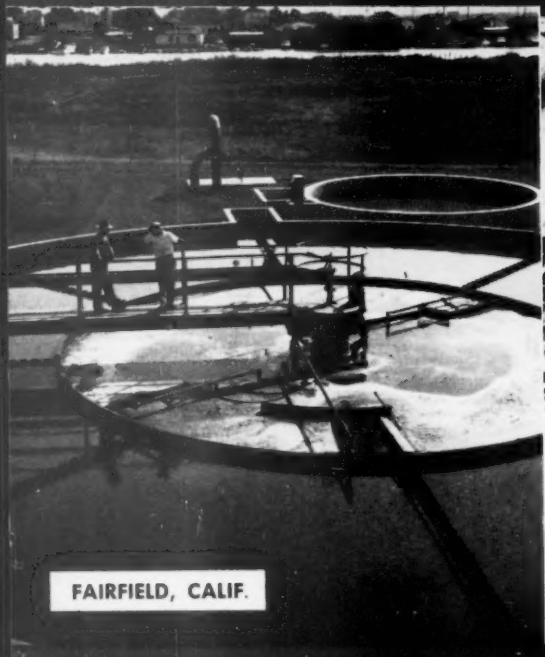
ARLINGTON, TEXAS





THE EIMCO CORPORATION

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Process Engineers Division
420 Peninsular Avenue
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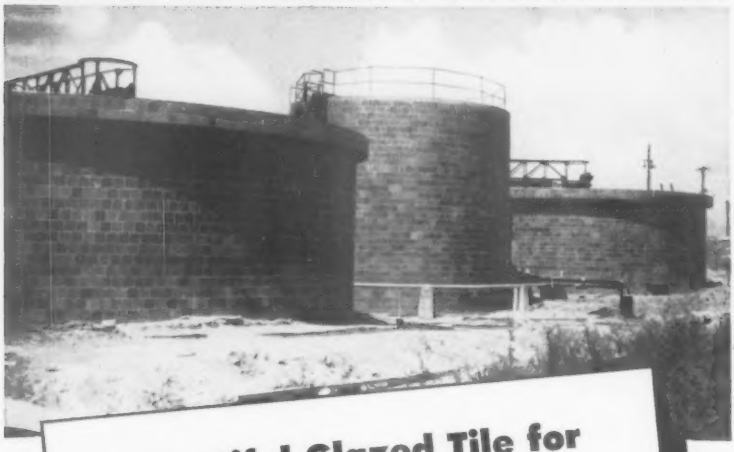
Effluent and Water Treatment Tanks



Beautiful Glazed Tile for Complete Corrosion Resistance

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Comparable in Cost to Concrete or Steel... No Continuing Maintenance

Stebbins SEMTILE® and SEMBLOK® tanks are, in effect, reinforced concrete structures faced on both sides with vitrified tile. No form work is required. Contours and dimensions can be varied to fit all types of specialized equipment.

Installations can be made under a contract which covers everything from the original design, based on full knowledge of the chemical, physical and mechanical requirements, to the finished job ready for use.

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Specialists in Design, Installation and Servicing of Linings and Tile Tanks

What's the best way
of getting water
from here...
to here?
(turn the page)

CAST IRON PIPE

America's greatest water carrier

Installation of 2000 feet of 12-inch mechanical joint cast iron pipe along state highway.

Why do we say that?

This year, as every year, more miles of underground cast iron water mains are in use than all other kinds of pipe combined.

Furthermore, more miles of cast iron water mains are now being purchased and laid than of any other kind of pipe.

Yes, cast iron is always the favorite. A recent impartial survey showed that consulting engineers and water utility officials prefer cast iron pipe for underground water distribution by an overwhelming majority.

Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 3440 Prudential Plaza, Chicago 1, Ill.

Eight-inch cast iron pipe ready for installation of 2-main water system in new subdivision.

Installation of 60-inch flanged pipe and fittings for circulating condenser water in a power plant.

Additions to a municipal water system totaled 116,080 feet of slip-on joint cast iron pipe in 6-, 10- and 12-inch sizes.

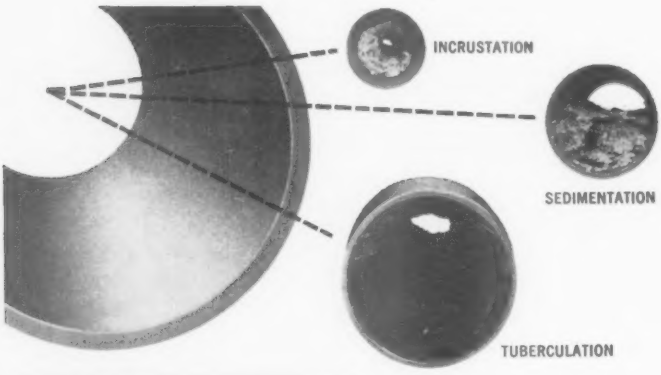
Private water company main extension of 6-inch slip-on joint pipe for housing development.

What are its advantages?

- *Long life.* The cast iron pipe you install today will be performing economically a hundred years from now.
- *High-capacity flow.* Cement-lined cast iron pipe will deliver the full-rated flow all through the years. No other pipe, size for size, can carry more water.
- *Corrosion resistance.* Long life proves it. Most water utilities are still using the first cast iron pipe they installed.
- *Great beam strength.* Cast iron pipe resists the effect of heavy traffic, shifting soils.
- *Tremendous load resistance.* Six-inch cast iron pipe (Class 150) withstands a load of nearly nine tons per foot!
- *Pressure-tight joints.* You have a complete choice of leakproof, easy-to-assemble joints. You need a minimum of tools and work crew.
- *Ease of tapping.* No tapping saddles needed. Takes threading best of all kinds of pipe.

...good reasons for <u>you</u> to choose

CAST IRON PIPE
THE MARK OF THE 100-YEAR PIPE



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National knows how to clean the difficult jobs, including hard incrustations, unusual obstructions and pipes of unusually large or small diameter.

National knows how to clean long runs with a minimum number of pipe entries.

National knows how to avoid trouble, such as can occur from improper provision for drainage of flush water from large mains or from the use of excessive pressures.

National knows how to clean so thoroughly that restoration of 95% of the original pipe capacity is guaranteed.

National Know-How comes from over 40 years of experience cleaning water mains.

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CUTS SEWAGE TREATMENT COSTS UP TO 27%

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- Lowest capital costs
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- No falling off in efficiency
- No diffusers, blowers, or air cleaners
- No diffuser cleaning
- No expensive blower housing

Call in your Yeomans representative to fill out details on the cost story, or request the performance reports offered at right.

YEOMANS

☐ Cavitator® Engineering Report: technical analysis and report covering cost and performance.

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Please send me copies of the reports checked above.

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Organization_____

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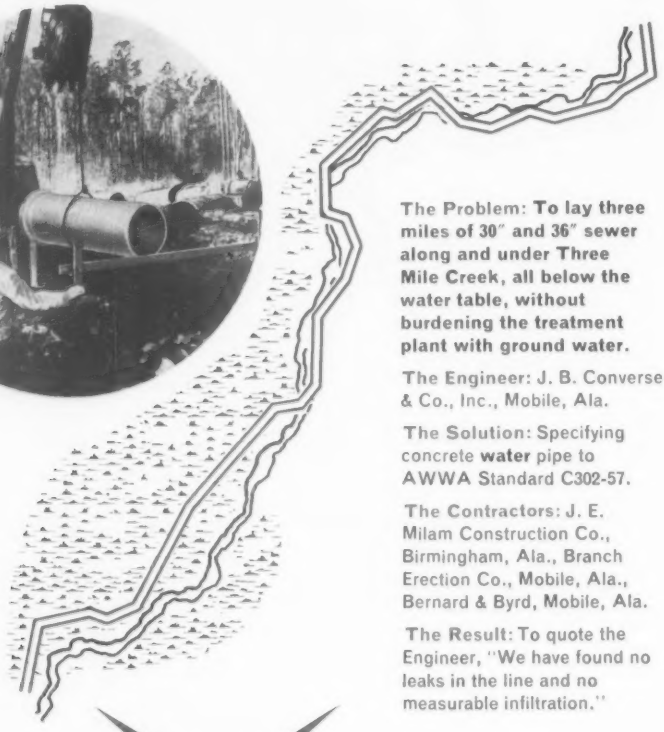
T-5923

the problem...



The Problem: **To lay three miles of 30" and 36" sewer along and under Three Mile Creek, all below the water table, without burdening the treatment plant with ground water.**

The Engineer: J. B. Converse & Co., Inc., Mobile, Ala.

The Solution: Specifying concrete **water** pipe to AWWA Standard C302-57.

The Contractors: J. E. Milam Construction Co., Birmingham, Ala., Branch Erection Co., Mobile, Ala., Bernard & Byrd, Mobile, Ala.

The Result: To quote the Engineer, "We have found no leaks in the line and no measurable infiltration."

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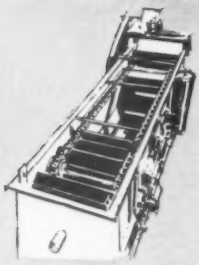
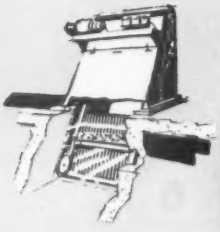


Typical modern waste treatment plant completely equipped with REX Sanitation Equipment.

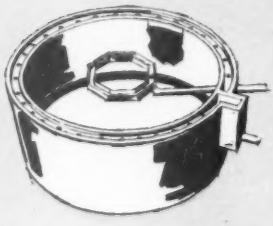
REX FLOAT-TREAT... Treatment by dissolved air flotation.

TRAVELING WATER SCREENS ...Fine screening for process or waste water.

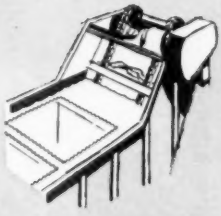


REX BAR SCREENS... Coarse screening for large solids removal.

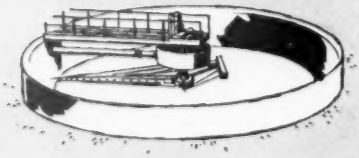
REX WASTE TREATMENT EQUIPMENT ASSURES PROVEN PERFORMANCE...MAXIMUM ECONOMY... SOUND ENGINEERING...MODERN DESIGN



REX RIM-FLO CLARIFIERS... Maximum settling efficiency in a circular tank.



REX VERTI-FLO CLARIFIERS... Maximum settling efficiency in a rectangular tank.



REX SLUDGE COLLECTORS... Suction or scraper type...round or rectangular tanks.

Whatever the problem in waste treatment, whether it's the removal of solids or the recovery of valuable products, CHAIN Belt Company is ready with the economical answer ...an answer developed through nearly 30 years of practical experience and research.

CHAIN Belt offers the best in modern methods of treatment as well as a complete line of modern, quality equipment. Rex can offer the right type and size for nearly every requirement, from a tiny steel tank package plant to large multi-unit concrete tank installations.

Flexibility in choice of process and equipment assures the lowest possible plant cost, lowest operating and maintenance cost consistent with top performance.

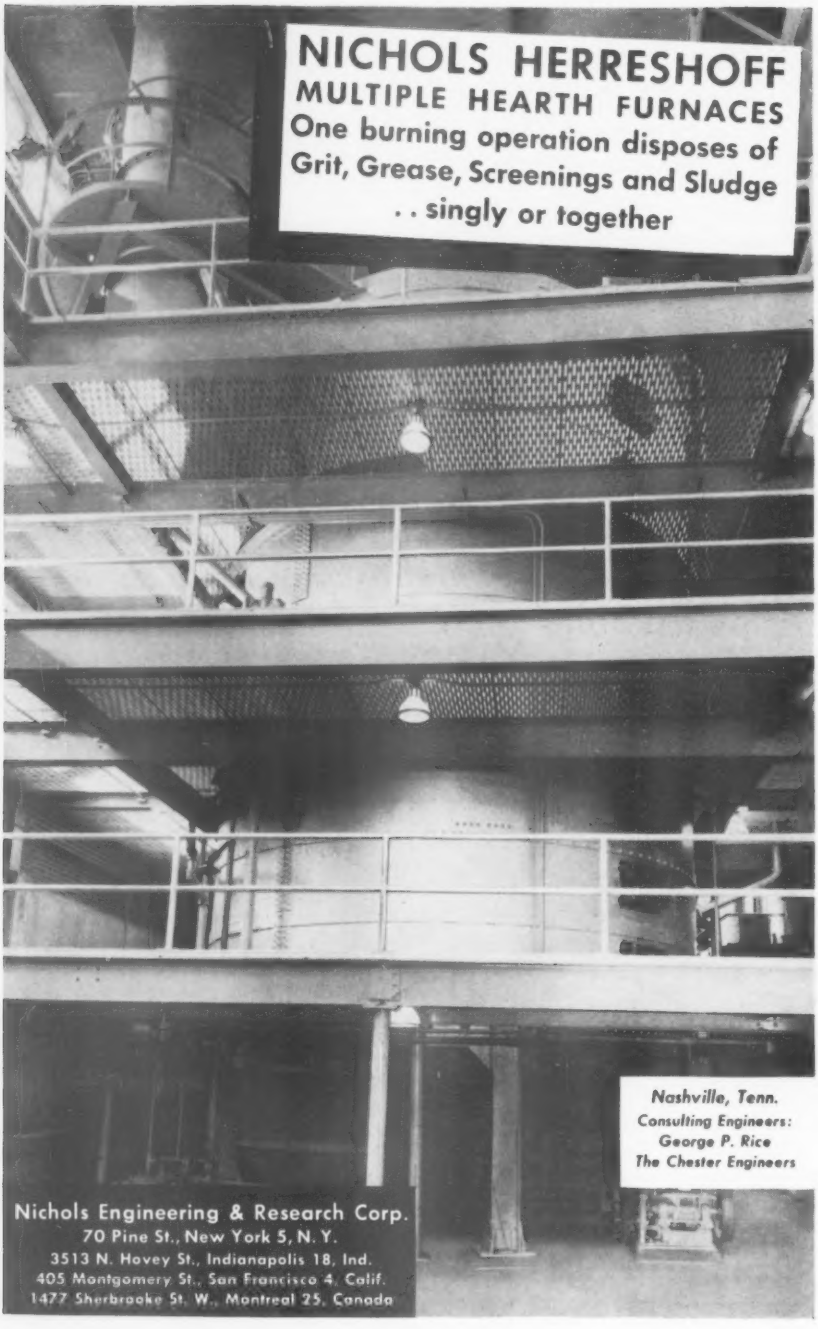
Rex processes and equipment reduce pollution, save valuable products and water with efficient use of space and facilities. Existing structures may often be utilized to provide modern treatment with slight modification.

The CHAIN Belt technical staff can assist in the evaluation of any waste treatment problem. Laboratory and field investigations will be performed and waste analyzed for proper equipment selection. Laboratory test service is available, as well as pilot units for field tests.

Call the nearest Rex Field Sales Office for complete information on the waste treatment equipment shown here and many other types. Or write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wis.

REX®

SEWAGE AND WASTE TREATMENT EQUIPMENT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MULTIPLE HEARTH FURNACES
One burning operation disposes of
Grit, Grease, Screenings and Sludge
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Exclusive FLUID-TITE Coupling joins lengths of varying crushing strengths and sizes. Assemble in any weather—without heavy machinery.

"K&M" ASBESTOS-CEMENT SEWER PIPE

Infiltration-proof at 25 psi pressure!

Exclusive, patented "K&M" FLUID-TITE Coupling maintains a permanently infiltration-proof seal under severest field conditions.

This is true even when "K&M" Asbestos-Cement "FLUID-TITE" Sewer Pipe is under deflection, or is buried at various depths under heavy backfill. Tests prove this infiltration-proof pipe can withstand 25 psi external water pressure.

There's minimum maintenance with "K&M" Asbestos-Cement FLUID-TITE Sewer Pipe. It reduces treatment loads and costs. Requires fewer periodic inspections and cleanings.

Eliminate the problem of infiltration with tested and proven "K&M" Asbestos-Cement FLUID-TITE Sewer Pipe. Write to us today.

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BEST IN ASBESTOS

KEASBEY & MATTISON
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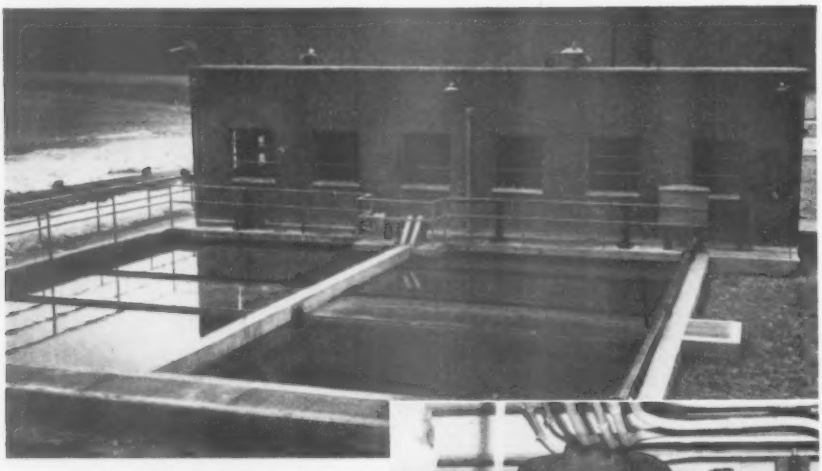
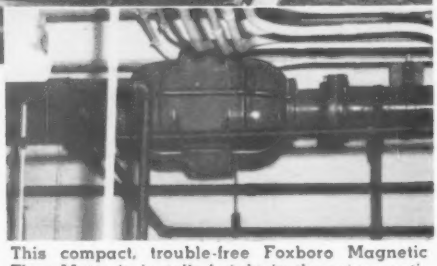
City of Sidney, Ohio gets . . .

Smooth Measurement of Sludge Magnetically



with FOXBORO MAGNETIC FLOW METER

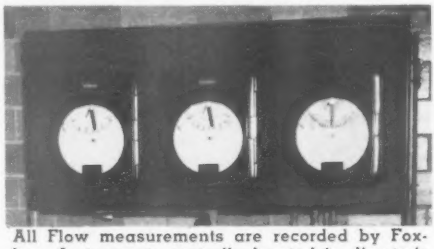


This compact, trouble-free Foxboro Magnetic Flow Meter is installed right in the return activated sludge line at Sidney, Ohio's modern new sewage plant. There's nothing in the line to obstruct flow . . . no pressure taps or purges.

No line restrictions — no pressure taps to plug. With the Foxboro Magnetic Flow Meter there's nothing in the line to cause pile-up of solids. And you can forget about purging of pressure taps — there aren't any. Electric cable carries measurement signal to remote Dynalog* Electronic Recorder, providing a direct magnetic measurement of fluid velocity.

Get full details on this unique development in flow meters. Write for Bulletin 20-14B. **The Foxboro Company, 8810 Neponset Ave., Foxboro, Mass., U. S. A.**

*Reg. U.S. Pat. Off.



All Flow measurements are recorded by Foxboro Instruments centrally located in director's office at Sidney plant. Shown above are: (l. to r.) Air Flow Recorder with integrator; Sewage Flow Recorder with integrator; Dynalog Recorder for return activated sludge.

FOXBORO *FIRST in FLOW*

Reg. U.S. Pat. Off.

Announcing a New

FERRIC SULFATE PLANT

These new facilities now in operation at Copperhill, Tennessee substantially increase our production of Ferri-Floc and will permit us to supply the increased demands for this superior coagulant at all times.

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THE COAGULANT WITH THE PLUS FEATURES

Excellent Taste and Odor Control
Increased Filter runs
Coagulation over Wide pH range
Rapid Floc Formation
Turbidity Removal
Manganese and Silical Removal
Bacteria Removal
Ease of Operation
Efficient and Economical

AVAILABLE IN BULK, AND ALSO IN DOUBLE LINED POLYETHYLENE BAGS AT NO EXTRA COST.

FREE BOOKLET — We will send you, without charge, a 38 page booklet that deals specifically with all phases of coagulation —Just make request on your firm's letterhead.

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New steels are born at Armco

As the 120-foot outfall was lowered into place, it was joined to remaining portion of existing outfall.

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Supt., Aurora Sanitary District
Walter E. Deuchler Co., Aurora
Consulting Engineers

Engineers will be interested in Bulletin 25-S-91 for details on GASLIFTERS; and Brochure 25-S-11336 for complete report on GASLIFTER operating results at a full scale plant installation. Write for your copies.

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THE BIOLOGICAL CONTROL OF ENCLOSED ENVIRONMENTS

By C. G. Golueke, W. J. Oswald, and P. H. McGauhey

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The launching of the first earth satellites and the rapid development of space technology emphasize the need to prepare for the eventual day when man embarks on extended voyages into space. As rocket technology approaches the state where man-bearing ships can be projected into outer space, it is important to begin immediately an intensive study of all possible means of enabling man to live for extended periods inside ships or stations suspended in or moving through an environment which would be instantly lethal to him. It is obvious that one of the essential conditions for survival in such a situation is the rigid control and the constant renewal of the environment within the ship. On extended trips this control and renewal will by its very nature involve not only the disposal of the crew's solid, liquid, and gaseous wastes, but also the reconversion of these wastes into usable products. Such reconversion is necessary in order to minimize the load which must be projected from the earth at the time of launching.

It is essential to recognize at the outset that environmental control requires a continuing source of primary energy. This energy source must either be projected from the earth along with the ship's crew, or be external to the ship itself. The power capacity required per man is ordinarily estimated to be about 10 kw, and thus the energy requirement is more than 200 kwhr/day/man. Needless to say, environmental control by conventional fuels is barred by simple logistics for any but the most perfunctory voyage into space. Two alternatives present themselves—atomic energy and solar energy. Use of atomic energy would presumably require a heavy generating plant plus either weighty shielding or remote positioning to protect the crew from radiation, in which case the plant would be shielded in common with the power source for the ship. The nuclear fuel requirement, however, would be only about 10 to 15 g/yr/man (1). Solar energy has the limitation of varying with distance from the sun and could probably be used directly for biological purposes only after filtering out the intense ultraviolet and other short-wave components.

Review of Control Methods

The environment within a space ship or station might be regulated either by chemical-mechanical means, by biological means, or by a combination of the two. Chemical-mechanical methods would include the use of lithium hydroxide for absorbing carbon dioxide, and of liquid oxygen to meet the respiratory requirements of the crew. Liquid wastes could be distilled to remove salts and to recover water. Moisture evaporated from the surface of the skin or exhaled by man would be recovered by condensation. A chemical-mechanical method of environ-

mental control has the advantage of being compact, easily manipulated and regulated, and may require less total energy than biological methods. These advantages, although impressive for short voyages, are minimized or lost with the extension of the time period during which the atmosphere must be controlled, because the weight and volume of working materials increase in proportion to the increase in length of voyage; whereas, the weight of a biological system would remain constant.

Most of the existing physicochemical methods are characterized by grave disadvantages inherent in the systems. An example is the lithium hydroxide-lithium carbonate system for carbon dioxide exchange, which has been described by Gustavson (2) and Konecci (3), and which at present, is probably the most feasible non-biological method. In this system, lithium carbonate produced by absorption of carbon dioxide would be converted back to lithium oxide by heating, and the evolved carbon dioxide would be compressed within the ship or released into space. In the former case, heavy compressors would be required, while in the latter, the result would be a loss in mass of the ship, and ultimately, a lowering of the atmospheric pressure within it. A system in which wastes are oxidized chemically would result in the gradual accumulation of the stabilized products, which would require heat energy for reconversion. Incineration of wastes would require oxygen, while gasification of wastes without oxidation would produce toxic gases such as ammonia.

Water Requirements

Meeting the water requirements of the crew ranks in importance with the provision of adequate gas exchange in controlling an enclosed environment. Therefore, in evaluating practical systems for regulating and renewing enclosed environments, it is necessary not to ignore one of the more homely, yet basic requirements for the well-being of modern individuals; namely, the essential part played by minimal quantities of water in personal hygiene and sanitation. It is true that for simple survival a man can exist on a little less than one gallon of water per day (including intake with food and by drinking); but for the avoidance of skin discomforts and skin diseases, which multiply with time, he must bathe frequently. An additional gallon of water per day would be required for cleansing the hands and face for a simple sponge bath. Finally, because materials will have to be used over and over again, it is essential to provide for cleansing of clothing and eating equipment. These operations might require from two to three gallons per man. It appears, therefore, that for a man to dwell comfortably in an isolated environment for an appreciable length of time, he will require several gallons of water per day. The most obvious means of insuring an adequate daily water supply and of maintaining a low launching weight, would be to carry only an amount equal to the crew's needs for a given period of time, and then to reuse the supply continually by reclaiming it from liquid wastes in a process which would reclaim water at the same rate as needed. If this were done by chemical-mechanical means, distillation would seem the obvious choice; but it has many disadvantages, among which are the large amount of heat required and the release of ammonia. As an alternative, the waste liquids could be purified by resins in passage through an ion-exchange column. The disadvantage of such a system would be the weight and bulk of the resins and of the chemicals required to regenerate the resins. Both distillation and ion-exchange procedures have the disadvantage of reclaiming only the water fraction of the wastes. Waste organic solids must first be filtered out, and since their reclamation may be accomplished only by biological processes,

they would presumably have to be ejected from the ship or placed in storage. Furthermore, boiler scale and blow-down from distillation, as well as wastes from the regeneration of resins, would tie up chemicals in forms no longer suitable as nutrients for man. Hence, secondary systems would be required for the recovery of solid wastes; or their replacement in more usable form would have to be a part of the ship's stores, along with the compressed gas necessary to restore the internal pressure lost in periodically ejecting them from the vehicle.

Advantages of Biological Control

A biological system of environmental control would have none of these problems. The system not only would accomplish the necessary gas exchange of oxygen for carbon dioxide, but would also purify and reclaim the water from the liquid wastes with but little added power or weight requirements. That is, the one system would serve as a complete control of the environment. The control and renewal of the internal environment of a space ship by biological means would seem to be compatible with man's psychological and physical nature in that he has always been a part of such a system. The world is essentially an enclosed environment which is almost completely regulated and constantly renewed by biological means. Thus, there is no question that biological control of environment will function; the only question is, can these biological cycles be made to operate on a sufficiently small scale to be practical in a space ship? If it were possible to decrease the size of such a system to a volume which could be fitted into a space ship and insure its continued survival under the rigors of space travel, the crew could enjoy with a minimum of physiological and psychological readjustment the same biologically regulated environment to which they are normally adjusted.

A practical method for simulating the earth's biological system is shown in Figure 1. The system involves the exclusive use of single-celled green algae to carry out the reactions of the green plants in the plant kingdom, while man, aided by bacteria, would carry out the role of the animal kingdom. In the system, all solid and liquid wastes, excretory and otherwise, are converted by bacteria through oxidation into products which serve as nutrient for the algae and the water is rendered suitable for reuse. Carbon dioxide given off by the crew and by the bacteria is synthesized by the algae into new cellular material with the use of energy in the form of light. In so doing, oxygen is released, which in turn, is used by the crew and by the bacteria. As the diagram indicates, the process is cyclic, except that algae are stored instead of being recycled as food. Because unicellular algae usually contain a high percentage of protein and relatively little carbohydrate, they could not be used exclusively as a foodstuff. Therefore, the algae would be stored, either in their entirety, or in an amount proportionate to the mass of food consumed.

Although the advantages of a biological system of environmental control in space ships and stations are obvious and widely recognized, work has been limited largely to one phase —the removal of carbon dioxide and the replenishing of the oxygen supply (1)(2)(3)(4)(5). The studies herein reported were therefore designed to treat the biological system as an engineered means of total control of air, water, food, and well-being, rather than merely as a gas exchange system in an isolated environment. They are an outgrowth of previous studies on the disposal of solid and liquid wastes by integrated algal-bacterial systems made by Oswald and Gotaas (6) and Oswald *et al.* (7) in the use of photosynthetic oxygenation in sewage treatment during the past few years.

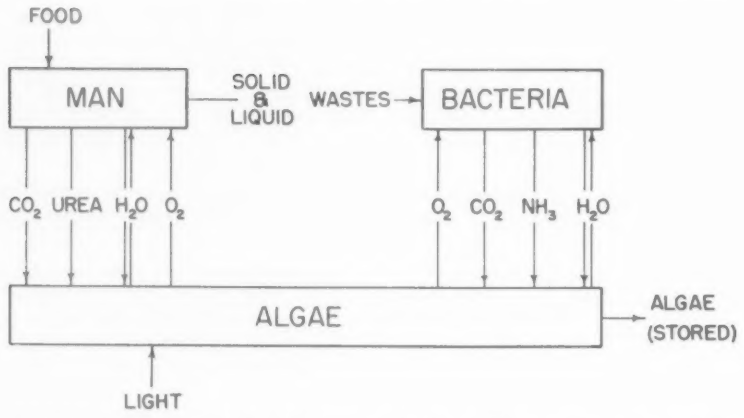


FIGURE 1.—Reactions and cycles involved in the complete control of an enclosed environment by a biological system involving man, algae, and bacteria.

Experimental Procedure

The investigation was divided into two studies. The first of these was concerned with determining those environmental conditions under which maximum algal growth and efficiency can be attained. As indicated in the general equation for photosynthesis

$$CO_2 + 2H_2O \xrightarrow{\text{light}} (CH_2O) + O_2 + H_2O \quad (1)$$

The gas exchange capacity of a photosynthetic system is a direct function of the rate of cell growth; hence, any set of conditions which would enhance cell growth would also result in an increase in the gas exchange capacity of the system. The second study was concerned with the waste treatment and reclamation aspects of the system.

Culture Development

The first step in developing a biological control is the isolation of groups of organisms capable of functioning at high efficiency under the wide range of environmental conditions to be encountered during the flight of a space ship. Thus, an important feature of the investigation was the use of mixed cultures of algae developed from strains encountered in high-rate wastewater stabilization ponds. Mixed cultures of algal and bacterial flora were used because the physiological characteristics and requirements of each group of organisms differ; therefore, it is reasonable to assume that a complex consisting of two or more groups of photosynthetic organisms would result in an increase in the tolerance of the culture as a whole to a wider spectrum of environmental conditions.

Environmental factors studied included temperature, carbon dioxide concentration, length of light duration per 24-hr period, detention period, and rate of light energy input. Suitable cultures were developed through the process of selective adaptation, *i.e.*, by exposing the strains of organisms obtained from high-rate stabilization ponds to the environmental conditions specified. As might be expected, a high rate of kill accompanied the first exposure, but eventually a culture of algae and bacteria was developed which operated efficiently in a temperature range from 20 to 40°C, and was capable of surviving brief exposures to temperatures of 48 to 50°C. No attempt was made to isolate pure strains of the organisms involved, but uni-

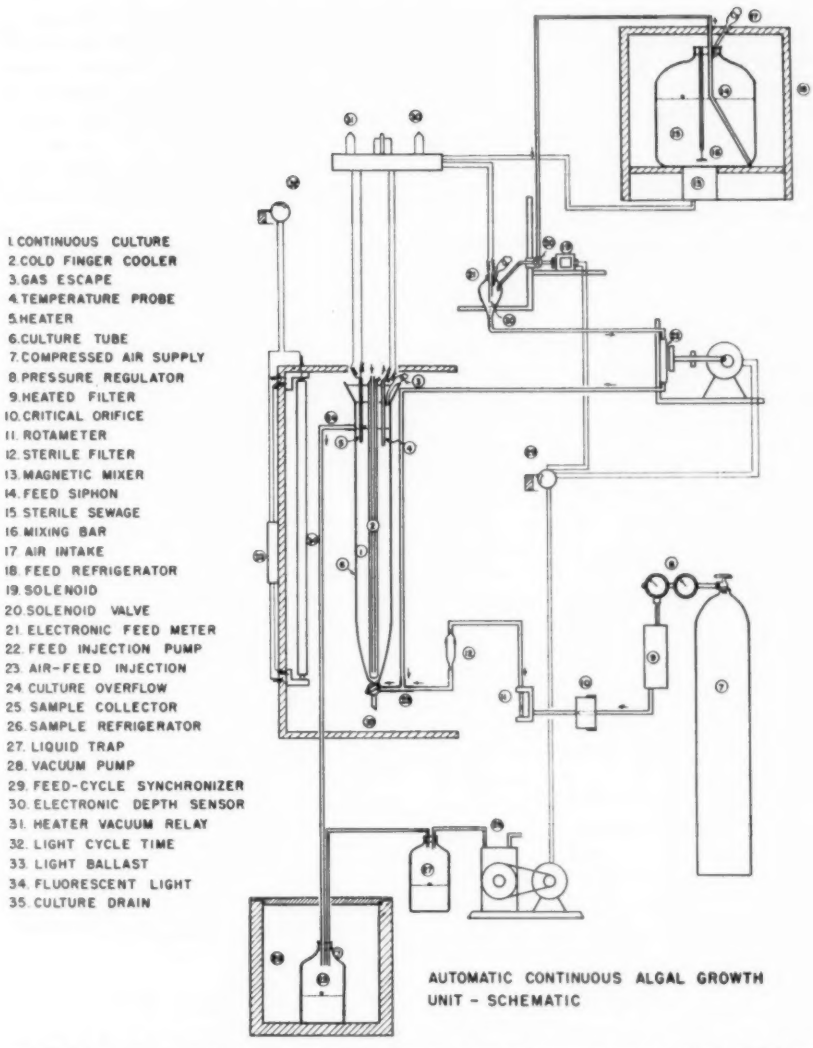


FIGURE 2.—Schematic diagram of growth units used in determining the effect of various environmental conditions on the efficiency and growth rate of algal cultures.

formity of inoculum was insured by maintaining the stock culture of mixed organisms under constant environmental conditions. Thus, the stock culture served as an enrichment culture for the organisms being studied. The net result was the maintenance of a uniform population of the algal groups *Chlorella* and *Scenedesmus* in the ratio of 5 or 6 to 1.

Experiments on the development of a temperature-resistant population of organisms—algal, bacterial, and protozoan—as well as those concerned with the study of environmental factors and with high density cultures, were made

in continuous automatic growth units (8) shown schematically in Figure 2. These units were designed so that experiments could be continued indefinitely, although a period of 10 days usually was more than adequate for the attainment of a "steady state." Six units were operated in parallel during each experiment. Each unit was equipped to maintain continuously a preset detention period, temperature, period of light duration, degree of light intensity, and rate of gas flow. Provision was made for varying strength and composition both of nutrient sewage and of gas used for mixing and as a source of CO_2.

Each experiment was initiated by transferring 4 liters of algal culture from the stock culture to an 11-l pyrex bottle. Two liters of raw sewage, strained through glass wool, were then added to the culture. The resulting suspension was enriched with urea (0.3 g/l of suspension) and an aliquot poured into each of the growth units. The cultures were illuminated with a single lamp for a period of two days to permit the algae to become adjusted to the radiation of the fluorescent lamps. At the end of this period the light was increased or diminished according to the conditions of the experiment. Feeding of cultures was not initiated until the end of the second day. At that time they were subjected to the conditions of the experiment for a period varying from 8 to 10 days. Daily observations were made of algal population and of the packed volume of the cultures.

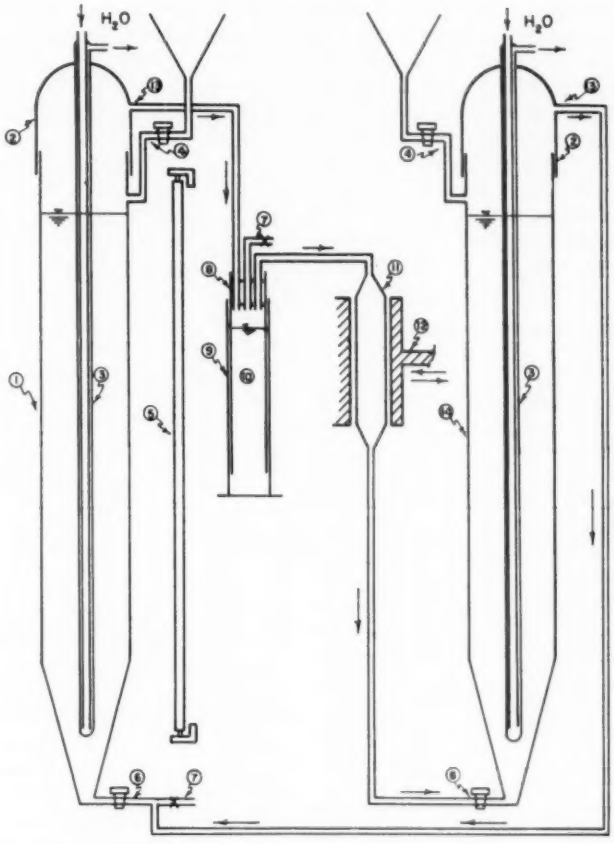
Domestic sewage enriched with urea was used as a nutrient for the cultures because such a mixture approximates the medium which would exist in a closed environment. The proper concentration of urea and the most suitable composition of the medium were determined from the results of preliminary experiments. The sewage was first sterilized in an autoclave; and a solution of urea in distilled water, sterilized by passage through a Seitz filter, was subsequently added. Urea was used as a nitrogen source because it eliminated the problem of phosphate precipitation which accompanies the use of ammonium phosphate, as well as the pH problem which characterizes media containing ammonium sulfate or nitrates.

Waste Treatment Aspects

Experiments involving the solid and liquid waste treatment aspects of the system were conducted with an integrated growth unit and activated sludge unit which are shown in Figure 3. Except during feeding time, the system was closed to the surrounding air, and the gases inside the system were recycled by pump, so that oxygen evolved during photosynthesis in the growth unit was passed through the activated sludge unit, while the carbon dioxide and ammonia released as a result of bacterial activity in the activated sludge unit were passed through the growth unit. Thus, practically all of the gases required for oxidation and for photosynthetic activity were obtained as a result of the activity of organisms in the system. The physical dimensions of the activated sludge and growth units were comparable to those used in experiments on the effect of the environment, namely one-liter capacity. The system was operated on a semi-continuous basis, in that culture liquid was removed and nutrient added once each day.

The growth unit was illuminated by a battery of nine 30-w fluorescent lamps having a combined energy flux of 117,150 cal/min/l. Temperature was maintained at 33 to 35°C in both the activated sludge and the growth units. Four lamps were kept burning continually, while five were turned off for a 3-hr period during each 24 hr to bring about possible beneficial effects resulting from the alternation of periods of light and darkness (9) (10).

Efficiency as used herein is the over-



1. GROWTH UNIT TUBE
2. GLASS DOME WITH GROUND GLASS JOINT
3. COOLING TUBE
4. FEEDING PORT
5. ONE OF 9 FLUORESCENT LAMPS
6. GAS INLET
7. SAMPLING PORT
8. TELESCOPING TUBE
9. GAS COLLECTOR
10. MERCURY
11. BROSEIT PUMP
12. RECIPROCATING ARM
13. GAS OUTLET
14. ACTIVATED SLUDGE UNIT

FIGURE 3.—Schematic diagram of the waste treatment unit.

all light energy conversion efficiency expressed as per cent. It is based on the ratio of chemical energy permanently fixed in the form of algal material each day to the visible light energy absorbed by the cultures during the day. Determinations of this overall photosynthetic efficiency were made according to the procedure described by Oswald (8).

Nutrient used in the waste treatment phase of the investigation was not sterilized. During early experiments, raw sewage obtained from the San Francisco Sunset Treatment Plant and enriched with 0.3 g/l of urea was used as nutrient for the growth unit. Later the amount of urea was increased to 0.6 g/l. The activated sludge unit received raw sewage enriched with 0.08

g/l (dry weight) raw sewage sludge. As the experiments progressed, however, fresh urine was substituted for the urea and fresh feces for the raw sludge, in concentrations appropriate to the conditions of the experiment. The feces used approximated that which might be expected under spaceship conditions, being obtained from an individual subsisting on a relatively roughage-free diet in which fat, seasoning, and salt were kept at a minimum.

Experimental Results

Gas Exchange

A detailed presentation of all of the experiments conducted as a part of the gas exchange phase of the study is not included in this paper. Only those results which have a direct bearing on environmental control in enclosed environments are reported. For experimental purposes environmental conditions were varied within the following ranges: (a) CO_2 concentration from 0.03 to 4 per cent; (b) detention period from 1 to 5 days; (c) periodicity (duration of light per 24-hr period), 40 to 80 per cent; (d) temperature, 20 to 40°C; and (e) light intensity, 1.6 to 28.6 cal/min/l.

1. *Efficiency.* The efficiency with which the algal cells transform light energy to new plant material is important because the more efficient the algae, the less light energy required. The lowest average efficiency obtained during the experiments was 2.2 per cent. This occurred when the environmental conditions of the culture were: (a) CO_2, 0.03 per cent; (b) detention period, 3 days; (c) periodicity, 14.4 hr/day; (d) temperature, 30°C; and (e) input light energy, 14.1 cal/min/l. The highest efficiency observed was 26.7 per cent, attained by increasing the CO_2 to 1 per cent and decreasing the detention period to one day. Most of the values for efficiency observed during the experiments were within the range of 11 to 15 per cent.

2. *Hourly yield.* When equilibrium is reached in a continuous culture, the average growth rate is a function of detention period and periodicity, which may be expressed by the equation

$$G_r = \frac{1}{Dh} \quad \ldots\ldots\ldots\ldots (2)$$

in which G_r is the growth rate in mg of algae produced per mg of algae in the culture, D is the detention period in days, and h is number of hours the culture is exposed to light per day. Inasmuch as the hourly yield is determined by the concentration of the culture and the hourly growth rate, the hourly yield may be expressed either as

$$Y_h = \frac{C_e}{Dh} \quad \ldots\ldots\ldots (3)$$

or as

$$Y_h = C_e G_r \quad \ldots\ldots\ldots\ldots (4)$$

in which Y_h is the hourly yield of algae in mg, C_e is the concentration of the culture in mg/l, and G_r, h, and D are as in Eq. 2. The upper practical level of the growth rate is limited by the minimum generation time of the organism involved; which in turn, is determined both by the genetic characteristics of the organism and by the environment to which it is exposed. The concentration of a culture is largely a function of environmental factors. Hence, to obtain maximum hourly yields of algae, environmental factors must be such that a concentration exists at the shortest detention period commensurate with the minimum genetic generation time of the organism involved.

In the present experiments, the maximum concentration attained was 1,454 mg/l at a growth rate of 2.4 per cent per hour; and the highest average growth rate was 7.6 per cent (generation time, 13.1 hr) at an algal concentration of 316 mg/l. All of the experiments showed that the denser the culture, the longer the required detention

TABLE I.—Characteristics of the Effluents from the Algal Growth Unit

Feed*		Detention† (days)	BOD		Dissolved Solids			Algal Conc. (mg/l)	Photosyn. Effic. (per cent)	Hourly Growth Rate (per cent)	Coliforms‡	
Urea (g/l)	Urine (ml)		Conc. (mg/l)	Removal (per cent)	Volatile (mg/l)	Ash (mg/l)	Volatile Removal (per cent)				Total per 100 ml	Removal (per cent)
0.3	—	12	14.0	88	209	155	59	4,500	1.7	0.37	—	—
0.6	—	12	3.5	97	—	—	—	—	—	—	—	—
—	50	12	4.7	99	254	560	31	4,500	1.7	0.37	—	—
—	50	6	5.1	99	271	572	32	4,700	3.1	0.76	2.4×10^6	99
—	50	5	7.2	99	211	549	27	4,200	3.8	0.92	2.3×10^6	99
—	50	4.5	12.0	99	323	592	35	4,150	4.4	1.05	2.9×10^5	99

* Additive is dissolved in or diluted with 1,200 ml fresh sewage.
† Detention period refers to the cells.
‡ Influent MPN greater than 1.09.

period. From the experimental data it may be safely concluded that the lengthy detention periods (72 to 96 hr) required for maintaining high culture densities resulted from an inadequate supply of light to all of the cells because of the culture unit design and the positioning of the lamps. By appropriate tube design and positioning of light source, concentrations as great as 5,000 to 6,000 mg/l might be maintained at detention periods as short as 12 to 24 hr. Elimination of the long detention periods for dense cultures is important where volume and weight requirements are strictly limited, because under such circumstances, highly concentrated cultures functioning at maximum efficiencies and growth rates would be needed.

Waste Treatment and Reclamation

A summary of the results obtained during the experiments on the solid and liquid waste treatment studies is given in Tables I, II, III, and IV. In Tables I and II are listed the more pertinent data on effluent characteristics of the algal growth units and the activated sludge units. A partial nitrogen balance is given in Tables III and IV. Each of the given values represents the average for a group of 3 to 5 experiments.

1. *Performance.* With one exception, as is indicated in Tables I and II,

TABLE II.—Characteristics of the Effluents from Activated Sludge Unit Operated on 1-Day Detention Period

Feed*		BOD		Dissolved Solids			Coliforms	
Raw Sewage Sludge† (g/l)	Fresh Feces† (g/l)	(mg/l)	Removal (per cent)	Volatile (mg/l)	Ash (mg/l)	Removal of Volatile (per cent)	Total per 100 ml	Removal (per cent)
0.9	—	8.0	99	—	—	—	—	—
0.8	—	5.3	99	232	189	63	—	—
0.75	—	5.4	99	197	181	61	—	—
—	2.0	385.0	59	—	—	—	7.3×10^5	99
—	1.2	29.0	96	202	401	82	2.4×10^6	99
—	1.1	15	98	186	367	92	4.3×10^6	99
—	1.0	14	98	198	373	91	1.5×10^5	99

* Solids were suspended in one liter of fresh sewage.
† Dry weight.

TABLE III.—Nitrogen Characteristics of the Cultures in the Algal Growth Unit

Feed*		Detention Period† (days)	Influent			Effluent			Nitrogen Removal	
Urea (g/l)	Urine (ml/l)		NH_4-N (mg/l)	Org-N (mg/l)	Total as NH_4-N (per cent)	NH_4-N (mg/l)	Org-N (mg/l)	Total as NH_4-N (per cent)	mg/l of N	Per Cent of Total N
0.3	—	12	51	37	58	6	31	16	51	58
—	35	12	48	233	17	57	11	84	206	74
—	50	12	53	380	12	84	8	91	336	79
—	50	6	72	350	17	93	7	93	351	83
—	50	5	37	426	8	87	25	78	351	76

* Additive is dissolved in or diluted with 1,200 ml fresh sewage.
† Detention period refers to the algal cells.

the BOD of the effluent ranged from 5 to 29 mg/l, and BOD removal from 96 to 99 per cent. The greater part of the dissolved solids of the effluents consisted of non-volatile solids, inasmuch as with one or two exceptions the volatile solids constituted only 27 to 35 per cent of the total dissolved solids. The low BOD values as well as the high ammonia content of the effluent indicate that ammonium salts and carbonates rather than unstable organic matter probably composed the greater part of the volatile dissolved solids.

Algal concentration was not greatly affected by a detention period beyond about 4 days. Experimental data showed an increase from 4,150 mg/l at a 4.5-day period to 4,500 mg/l at a 12-day period. Other experiments demonstrated that the drop becomes increasingly steep when the detention period is reduced below 4.5 days, falling to 3,200 mg/l at 4 days and to 2,000 mg/l at 3.5 days. Thus, algal growth rates of 0.0037 mg/hr/mg of algae (0.37 per cent) to 0.0105 mg/hr (1.05 per cent) were possible at concentrations of 4,000 to 4,500 mg/l. Although the per cent removal of coliforms was 99 per cent, the actual number remaining in the effluents was high, ranging from 1.5×10^5 to 73×10^8 per 100 ml. The high value was obtained when the activated sludge unit was overloaded with two grams of feces per liter of culture.

The sodium content of the liquid phase of the culture apparently was not affected by treatment, inasmuch as the sodium concentration of the influent varied only from 95 to 122 mg/l, as did that of the effluent.

Because the concentration of the culture made it impossible to determine the end-point in the titration procedure for the dissolved oxygen test, dissolved oxygen determinations could not be made with the effluent of the growth unit without treating it in such a man-

TABLE IV.—Nitrogen Characteristics of the Cultures in the Activated Sludge Unit

Feed*		Influent			Effluent			Nitrogen Removal	
Raw Sewage Sludge (g/l)	Fresh Feces (g/l)	NH_4-N (mg/l)	Org-N (mg/l)	Total as NH_4-N (per cent)	NH_4-N (mg/l)	Org-N (mg/l)	Total as NH_4-N (per cent)	mg/l of N	Per Cent of Total N
0.75	—	52	38	58	4	29	12	79	77
—	2.0	112	60	65	105	22	83	45	26
—	1.2	65	31	68	57	11	84	28	29
—	1.0	62	29	68	52	8	87	30	33

* Solids are suspended in one liter of sewage.

ner as to distort the true value of the dissolved oxygen. Consequently, determinations were limited to the effluent from the activated sludge unit. The range for dissolved oxygen was from 4.8 to 5.5 mg/l.

No routine determinations were made of the free oxygen and carbon dioxide in the system because the removal of the gas would have disrupted the gas balance within the system, and hence the degree of sewage conversion. However, occasional determinations showed that free oxygen was present in concentrations from 5 to 15 per cent; the lower value being observed within a few hours after feeding the system, and the higher value just prior to feeding. The CO_2 content varied from less than 1 per cent just prior to feeding to as much as 6 per cent not long after feeding. This variation is to be expected in a unit which is fed only once a day, because the composition of the gas is dependent on the metabolic activities of the organisms involved.

One of the characteristics of the effluents was a yellow pigmentation of the liquid, although the liquid itself was sparkling clear. The pigment was easily removed with the addition of activated charcoal. After reactivation by drying, the charcoal could be used repeatedly. The actual amount of liquid which could be cleared with a given amount of charcoal was not determined, although as many as 30 passes were made with one sample of charcoal without apparently diminishing the capacity of the sample to absorb pigment. The pigment may also be removed by coagulation with heat and subsequent filtration with a bacteriological filter.

As might be expected with a single daily mass feeding of activated sludge with raw human wastes, the odor of feces and urine was quite strong during the first hour after feeding, but within 2 or 3 hr, the fecal odor disappeared and was followed by a strong odor of ammonia, which lasted 4 or 5 hr. Thereafter, the activated sludge culture was characterized by the earthy odor indicative of the presence of actinomycetes. The algal culture itself was without detectable odor at any time.

2. *Nitrogen balance.* The nitrogen balance of the integrated waste treatment unit is given in Tables III and IV. In considering the data on the ammonia content of the activated sludge and of the growth unit sections, it should be remembered that because ammonia is a volatile gas, it probably was carried from one section to the other with the CO_2 and O_2 gases. Inasmuch as the pH of the cultures usually was between 7 and 7.5, only a small amount of the ammonia was tied up as ammonium salts, and hence, excepting that used as nutrient, the gas was free to circulate from one unit to the next. However, no increase in ammonia in the gas phase was noted.

As is shown in Tables III and IV, from 83 to 92 per cent of the nitrogen in the influent to the growth unit section was in the form of organic nitrogen. The situation was reversed in the effluent. In this, organic nitrogen constituted from 9 to 22 per cent of the total nitrogen. The conversion of organic nitrogen to ammonia nitrogen was accomplished by urea-decomposing bacteria which abound in fresh sewage. As may be ascertained from the nature of the nitrogen balance, these bacteria broke down the urea component of the urine to produce ammonia and CO_2, which were then used as nutrient by the algae. This ideal combination of ammonia and carbon dioxide in urine probably is the explanation of the excellent growth of algae on sewage enriched with it.

Organic nitrogen constituted only 32 to 42 per cent of the influent to the activated sludge section. The lower amount was due to the fact that most of the nitrogen in the influent to the activated sludge came from the sewage.

Because of the time of flow in the sewers, most of the urea originally present in the sewage was already broken down to ammonia and carbon dioxide before collection at the clarifier. On the other hand, the nitrogen content of the feces was not sufficient to affect to any great extent the proportions of ammonia nitrogen to organic nitrogen in the sewage.

The nitrogen content of the effluents was high, ranging from 68 to 152 mg/l, although the removal of nitrogen ranged from 58 to 83 per cent in the growth unit section, and from 26 to 77 per cent in the activated sludge section.

Discussion

It has been demonstrated that fresh feces and urine can be fed directly to the integrated algal-bacterial unit without inhibiting the organisms in the cultures. This is important because it solves the problem of conversion of these wastes, which hitherto has been regarded as highly complex (11)(12). An essential condition, however, is that there be sufficient algae in the culture and that the reproduction rate of the algal culture be sufficient to use the ammonia nitrogen as rapidly as it is released, because ammonia in excess is toxic not only to bacteria but to algae as well. Because of this toxicity it is necessary to place an active algal culture in series with an activated sludge culture, either by an interchange of gases, or by interchange of liquids, or by both when amounts of urine or fresh fecal matter in excess of that encountered in normal sewage are fed to the activated sludge. Moreover, this toxicity makes it imperative that the gas be kept circulating constantly through the activated sludge rapidly enough to prevent extended contact with the organisms in the unit. Another condition is that the rate of growth of algae be sufficient to result in the release of the oxygen required to oxidize the waste material. Because of these conditions, the amount of waste which can be treated by a given culture ultimately depends on the efficiency and growth rate of the algal culture.

Practical Evaluation

For the purpose of evaluating the experimental data in practical terms, consideration is given to the daily requirements of a man weighing 145 lb and in good health. Such a man at rest or at very moderate activity, requires from 408 to 681 g of oxygen each day. Inasmuch as approximately 1.6 g of oxygen are released with the synthesis of each gram of algal cell material, the algal culture would have to produce from 377 to 640 g of new algal material each day in order to meet the requirements of one man and provide a 50 per cent reserve of oxygen for safety. If an algal-bacterial growth unit were designed and equipped to produce cultures having concentrations of 5,000 mg/l, as were developed during the experiments, and which could function at the 7.6-per cent growth rates characteristic of the less dense cultures (100 to 300 mg/l), the required algal culture volume would be from 2.3 to 3.67 cu ft/man. In terms of weight this would be from 143 to 229 lb/man. Because the respiratory quotient of a man on a high protein diet is of the order of 0.801, the same culture would more than meet the carbon dioxide absorption requirement. The approximate total weight for culture and accessory equipment per man for oxygen production and carbon dioxide absorption might then be from 223 to 330 lb, depending on the amount of oxygen consumed by the individual. Myers (5) has estimated that the space requirements would be about 80 cu ft for culture and accessory equipment for a 230-liter algal culture operating at a growth rate of 4 per cent per hour and an efficiency of 10 per cent and lamps with an efficiency of 19 per cent. Applying his estimates to a culture of the

type mentioned above with algal concentration of 5,000 mg/l, efficiency of 15 per cent, and growth rate of 7.6 per cent/hr, the space requirements for equipment could be reduced by more than 50 per cent and would then be only 20 to 35 cu ft/man.

Gas Exchange

In the calculations involving gas exchange, extrapolations were used in applying data obtained from the experiments, in that actual efficiencies and growth rates obtained in cultures of low densities were combined with the high concentrations characteristic of dense cultures. This combination is assumed because improved design in growth unit tubes and apparatus and the development of lamps with high intensity will unquestionably make such results possible. In the discussion of the waste treatment aspects, estimates are based both on the performance of the system, in which the maximum photosynthetic efficiency attained was 4 per cent, the highest hourly growth rate was 1.05 per cent, and the algal concentration was 4,000 mg/l, and on the extrapolated results from the same system but adjusted to a 15-per cent efficiency and 7-per cent growth rate.

Required Amounts of Algae

Inasmuch as almost all of the BOD of the influent in the system was removed within 1 day, and the water requirement for a man is from 10 to 14 gpd, the maximum estimated algal culture required to process all of an individual's wastewaters each day will be 14 gal. However, treatment accomplished in the experiments was brought about by a culture operating at a low efficiency, low growth rate, and fed in single daily doses. It is possible to establish conditions under which higher efficiencies and growth rates could be effected, and with continuous feeding, the detention period could probably be reduced to one-half day. Because the same culture would be used both for gas exchange and for waste treatment, and the volume required for gas exchange is a minimum of 17 gal, there would be no need to reduce detention time; and hence, the system for waste treatment even with its present limitations is more than adequate.

A volume of 7.4 gal of algal culture would be adequate for processing the urinary excretions of one man. Inasmuch as the urea and other organic constituents of the urine serve as the major source of nutrient for the algal culture, the same culture used for gas exchange will serve to treat the urinary wastes of the crew. The experiments demonstrated that for continuous or semi-continuous cultures, fresh urine surpasses all other known nitrogen sources in suitability for algal growth.

The integrated activated sludge and algal growth unit with a total volume of 2 liters treated from 1 to 1.2 g of fecal solids (dry wt) per day. The average output of fecal matter by an individual is equivalent to 24 mg total solids (dry wt) per 2.20 lb of body weight per day (13). Although under space ship regimen, the special diet of the crew would probably result in limited fecal production, the average value of 24 mg per 2.20 lb body weight was used in the following calculations. Accordingly, a 145-lb man will excrete about 26 g/day. The system at its present efficiency, therefore, would require about 6.8 gal of algal culture, and an equivalent volume of activated sludge, or a total weight of 114 lb to handle the fecal wastes of one man. Increasing the efficiency of an algal culture to its potential of 15 per cent and the growth rate to 7.6 per cent, and providing for better distribution of gas throughout both sections, together with the expected reduction in fecal output per man, should reduce the volume and weight of the algal-activated sludge complex to at least one-fourth its present magnitude, or to a combined volume of 3.42 gal, or

28.5 lb for the entire unit. To this must be added some 20 lb required for equipment and control facilities. This phase of waste treatment cannot be integrated with the gas exchange culture, because fecal solids should be introduced into a unit having only activated sludge. It is true that fecal matter can be fed directly to algal cultures, and in fact would serve as an excellent nutrient, but the increased turbidity imparted to the algal culture would reduce the penetration of light into the culture, and thus impair its efficiency. Inasmuch as the activated sludge method of treatment by its very nature depends on an adequate supply of oxygen, a certain portion of algal culture must be set aside solely for providing oxygen to and using carbon dioxide and ammonia from the activated sludge culture. Therefore, the volume and weight of algal and activated sludge culture required to treat the fecal wastes must be regarded as being in addition to that needed for gas exchange and liquid wastes. This will not, however, exceed about 90 g of algae per day—less than 1/5 that required by each man.

Coliform Removal

Although 99 per cent of the coliforms were removed, the amount remaining in the effluent was high. However, the mere presence of coliforms, per se, does not make the effluent dangerous for adult human consumption. The coliforms are primarily indicators of fecal pollution, but they do indicate the need for sterilizing the water, which can be done either by heating briefly or by irradiation, either of which has been found to result in a 100-per cent kill. The water of condensation resulting from the contact of humid air with the surface of the cold wall of the vehicle could be used for drinking purposes. However, the possibility of intestinal-borne pathogens will be slight in a space ship providing the crew was thoroughly tested and inoculated against all diseases, and that "carriers" were excluded.

Pigmentation

The pigmentation of the effluent is not believed to be harmful, per se. This has been demonstrated by experiments in which the liquid effluent was given to rats in place of fresh water without causing any apparent harm to the animals. The principal disadvantage to its consumption by man appears to be psychological. Therefore, the water used for drinking purposes could be obtained from the ample supply of condensate, as described earlier. The high nitrogen content of this liquid does not appear to be objectionable because the individual would either assimilate it, or it would pass through his digestive system.

Salt

A logical first conclusion was that because of the high salt content of the excretory products of the crew, salt would gradually accumulate in the system until the microorganisms either are killed or the effluent water is rendered unpotable for humans. This would not happen because the entire environment would be closed and completely balanced. The salt intake of the crew comes only from the food they ingest and the water they drink. The food would be transformed into algae via the crew and the waste treatment system at the same rate at which the food is eaten, so that the amount of food destroyed through eating would be exactly equivalent to the amount of algae produced and stored. Algae being living organisms, require salt for their metabolism and growth, and on the average, in about the same proportions found in the organic matter consumed by the crew. If under dire circumstances the crew consumed some of the algae, the salt would then merely be recycled. The salt taken in from liquid will only equal that in the

drinking water of the crew, and inasmuch as this is recycled, no salt would accumulate. If through some quirk of metabolism of one of the groups of organisms involved, the salt content of the liquid should be increased, the small amount required to keep the salt level constant, could be distilled, and the resultant salt placed in storage. Any such chance salt accumulation would necessarily be only a fraction of the total salt intake, and hence very minute, because the average total salt intake per man is only about one-half ounce per day.

Nitrogen Cycle

As on earth, the nitrogen cycle in a space ship is of vital importance because nitrogen must be recycled to maintain the microbial populations in the environmental control system. An accurate nitrogen balance could not be made with the equipment used in the laboratory. During feeding and while centrifuging algae, nitrogen was lost to the surrounding air in the form of ammonia; and because daily analyses could not be made without unduly interfering with the conduct of the experiment, sufficient data were not obtained for arriving at a complete nitrogen balance. However, by extrapolating the results obtained in the experiments, it is possible to estimate the amount of algae which could have been grown on the nitrogen contained in the effluent resulting from treating a day's output of waste from one man under the conditions of the experiment. On that basis, about 55 g of algae (8 per cent nitrogen) could have been produced with the unused nitrogen. If the 34 g of algae produced per day (1 g of algae per day on 50 ml urine in the growth unit and the volatilized ammonia nitrogen carried over from the activated sludge unit) were added, the potential yield would have been 89 g of algae each day under the conditions of the experiment. However, the true potential is much higher. Assuming a daily output of 12.14 g of nitrogen per man per day (13), the true potential would be 152 g of algae (8 per cent nitrogen). In addition to the loss of nitrogen, the difference in the two values also is accounted for by the variation in nitrogen output between individuals, as well as the daily variation in the same individual. It is evident, however, that since the cultures must remain in equilibrium some concentration of nitrogen is essential.

Even with the higher potential yield of algae, the amount of nitrogen contained in the wastes would not meet the nitrogen requirement of all of the algae needed in the waste treatment gas exchange system. As pointed out, gas exchange requires 255 to 425 g of algae each day, as against the potential of 152 g. The gap can be bridged in one of two ways or by a combination of the two. Algae can be cultivated in such a manner as to reduce their nitrogen content by extending the detention period or by retarding the growth rate. Such a change would not be desirable, however, because short detention periods and high growth rates are necessary for producing algae having the efficiency and growth rate required. The other solution is to feed the crew a high-protein diet. Because the nitrogen output by an individual approximates that of his intake, the protein content of the crew's diet would have to be increased from the usual 12 per cent to about 35 to 40 per cent. In other words, the nitrogen content of the dietary intake of the crew should equal that of the algae. Some of this nitrogen intake could be met by recycling a portion of the algae through the crew, *i.e.*, having the algae serve as part of the crew's diet. If such a high protein diet should prove unfeasible because of considerations of health, then part of the nitrogen requirements of the algae could be met by carrying a supply of urea or nitrate sufficient to fill the need. It is possible that some optimum balance could be found be-

tween detention period and nitrogen in the crew's diet. A study of this important factor would require pilot plant experiments in which the various combinations would be tried on crews actually living in a simulated station.

Comparison of Systems

For the sake of comparison between the relative weight requirements of a biological system of complete control of the environment with those for a chemical-mechanical system of control of only the gaseous environment, an arbitrary length of travel of three weeks is selected. The calculations for the biological system are based on the potentials demonstrated in the present experiments; and those for the chemical-mechanical method, on specifications at present available. The total weight per man of culture (bacterial and algal) and equipment for the biological system will be from 304 to 411 lb depending on the O_2 consumption of the individual (223 to 330 lb for gas exchange, 48 lb for fecal treatment, and 33 lb for bacterial needs). Assuming the same rate of oxygen consumption, the weight of the gas supply, absorbent, and containers and equipment for gas exchange alone by a chemical-mechanical system would be from 333 to 487 lb/man.

Other Problems

Many basic problems remain to be solved before the biological control of enclosed environments can be applied to space ships. The answer to some of the problems will be gained with further development of present-day technology, others will require radically different approaches. An example of the former is the provision of power for operating the plant, both with respect to movement of liquids and the supply of the required light energy. It appears that solar energy may be an adequate source of power for permanant stations established within a belt from 60 to 140 million miles from the sun, a zone which encompasses the orbits of Venus, Earth, and Mars. But for trips to the major planets and beyond the solar system it will be essential to supply energy by means of an atomic reactor. If an atomic reactor is used, from 10 to 15 g of fuel will be required per year per man to supply the energy requirements of a biological control system (1). The weight of shielding presumably need not be large because the power system would be attached at a distance away from the ship. In a solar-powered station, collecting surfaces for solar batteries would be distributed over or made a part of the exterior of the vessel itself and on projecting fins. In general, the required volume of the vehicles will be large enough to provide sufficient surface area (a maximum of 15 sq m/man) for adequate exposure of the algal culture to the sun, inasmuch as the algae would be grown in the peripheral zone of the vehicle. In atomic powered ships, the surface area per man in both power and culture surface would be about 10 sq m or less. Data on liquid-gas transfer in such systems is of vital concern and may be the factor which will determine the culture area. The design of windows to admit solar energy to the algal cultures, and the movement of gases and liquids in a weightless environment are vital parts of future research. But at present, the major problem appears to be placing and locating the enclosed environment in its orbit. Once there and fabricated and populated with adequate numbers of organisms, there is no obvious reason why the biological system of environmental control should not function as long as it is protected from damage or from lethal radiation.

Summary and Conclusions

A survey of the chemical and mechanical, and biological means of environmental control was made, and the advantages and disadvantages of each

were indicated. A chemical-mechanical process of control is characterized by ease of regulation and manipulation, as well as compactness. On the other hand, the cyclic nature of the biological system results in greater savings in weight and volume on extended trips or in space stations.

As a part of the experiments, strains of organisms, algal and bacterial, were developed which could thrive equally well at temperatures ranging from 20 to 40°C, could withstand temperatures as high as 48 to 50°C for periods of 1 to 3 hr without injury, and also were not affected adversely by sudden changes in temperature within the range 20 to 45°C.

Efficiencies attained in the studies on gas exchange ranged from 2.2 to 26.7 per cent, with the average varying from 11 to 15 per cent. Hourly growth rates varied from 1.3 to 7.6 per cent. If the efficiency of 15 per cent and hourly growth rate of 7 per cent routinely obtained with algal cultures having a concentration of 300 mg/l could be combined with a culture having a concentration of 5,000 mg/l, the total space and weight requirements for culture, equipment, and power plant to supply the gas exchange needs of 1 man would be from 223 to 330 lb, depending on the oxygen consumed.

Two types of detention period were used in the waste treatment study, a 1-day period for the liquid phase and a 4.5- to 12-day period for the algal cells. BOD removal was almost complete within a 24-hr period despite BOD values of influent as high as 1,200 mg/l. The BOD of the effluents varied from 3.5 to 29 mg/l, with the majority at less than 10 mg/l. At photosynthetic efficiencies from 1.7 to 4.4 per cent and growth rates of 0.37 to 1.05 per cent per hour, 1 to 1.2 g of fecal solids (dry wt) and 50 to 60 ml urine per 2 liters of culture (1 liter of algal culture and 1 liter of activated sludge culture) were processed each day. Operating the system under conditions at which an efficiency of 15 per cent and hourly growth rate of 7 per cent could be obtained, and providing for effective distribution of gas through the units, would reduce the volume and weight requirements of the cultures required for treatment of fecal matter of one man to a maximum of 3.42 gal or 28.5 lb, and the entire fecal treatment unit (culture and apparatus) would then weigh about 18 lb/man. The same culture used for gas exchange would be used for treating all wastes other than fecal, and hence no additional culture would be needed for them.

The total weight of the constituents of a biological system of environmental control required for a 3-wk voyage or sojourn would be from 304 to 411 lb. This estimate includes the entire weight required for both gas exchange and waste treatment, *i.e.*, complete environmental control.

References

1. Bassham, J. A., "Use of Controlled Photosynthesis for Maintenance of Gaseous Environment." Univ. Calif. Radiation Lab., Rept. for Contract No. W7405-eng-48, Reference UCRL-2707 (1954).
2. Gustavson, J., "Synthetic Atmosphere for Space Ships." *Astronautics*, **2**, 48 (1957).
3. Konecci, E., "Human Factors and Space Cabins." *Astronautics*, **3**, 42 (1958).
4. Fennon, R. M., "Man's Milieu in Space: A Summary of the Physical Requirements of a Man in a Sealed Cabin." *Jour. Aviation Med.*, **25**, 612 (1954).
5. Myers, J., "Basic Remarks on the Use of Plants as Biological Gas Exchangers in a Closed System." *Jour. Aviation Med.*, **25**, 407 (1954).
6. Oswald, W. J., and Gotaas, H. B., "Photosynthesis in Sewage Treatment." *Trans. Amer. Soc. Civil Engrs.*, **122**, 73 (1957).
7. Oswald, W. J., Gotaas, H. B., Golueke, C. G., and Kellen, W. K., "Algae in Waste Treatment." THIS JOURNAL, **29**, 4, 437 (Apr. 1957).
8. Oswald, W. J., "The Influence of Physical Environment Upon the Over-all Efficiency of Light Energy Conversion by *Chlorella* in the Process of Photosynthetic Oxygenation." Unpub. Doctoral Diss., Univ. Calif. (1957).

9. Tamiya, H., Sasa, T., Nikei, T., and Ishibashi, S., "The Effect of Variation of Day-Length, Day and Night Temperatures and Intensity of Daylight Upon the Growth of *Chlorella*." *Jour. Gen. Appl. Microbiol.*, **4**, 298 (1955).
10. Golueke, C. G., and Oswald, W. J., "Preliminary Studies of Biological Control of Enclosed Environments." Progress Rept. No. 1, Sanitary Eng. Res. Lab. and School Public Health, Univ. Calif. (1958).
11. Brockman, M. C., Heneck, A. S., Kurtz, G. W., and Tischer, R. G., "Closed Biological Systems for Space Feeding. II. System 3." *Food Tech.*, **12**, 453 (1958).
12. Brockman, M. C., Heneck, A. S., Kurtz, G. W., and Tischer, R. G., "Closed Biological Systems for Space Feeding. I. Systems 1 and 2." *Food Tech.*, **12**, 449 (1958).
13. "Handbook of Biological Data." W. B. Saunders Co., Philadelphia and London (1956).

FLORIDA OPERATORS RECEIVE AWARDS

At the 27th Annual Water and Sewage Treatment Plant Operators Short School, held in June at the University of Florida, David B. Lee, Director of the Bureau of Sanitary Engineering, Florida State Board of Health, is shown at left with the sewage treatment plant operators annual award winners for the best operated treatment plants in the State for the year 1958–59.

Awardees, from left, are: Sam P. Robinson, Lake Wales (trickling filter plant serving less than 10,000); Dries Vandenburg, Clearwater (activated sludge plant serving less than 10,000); C. M. Courson, Tampa (best operated plant—any class); W. C. Tims, Coral Gables (activated sludge plant serving more than 10,000); Perry A. Cessna, Bradenton (trickling filter plant serving more than 10,000); and Thomas E. Wagoner, Albert Whitted Plant, St. Petersburg (primary plant serving more than 10,000).

BETTER PUBLIC RELATIONS IN WASTE HANDLING PROGRAMS *

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It has been said that the attainment of clean water is the highest form of civic excellence and its achievement should be every community's number one project. Realization of this objective demands a high degree of technical competence and skill on the part of all who are actively engaged in the sewage and industrial wastes field. In addition to the technical know-how required to solve increasingly complex waste disposal problems, however, another skill is needed. This in the skill of achieving effective communication with the public.

The public is in a unique position. It has itself created the waste problem and, at the same time, it holds the ultimate power required to solve it. If it remains indifferent to a problem, that problem is likely to remain unsolved. The American public tends to be tolerant, patient, and obsessed—almost fanatically—with a sense of fair play. But its patience is not without bounds, its tolerance is not endless, and its sense of fair play does have limits. When the American public becomes aroused to the fact that a particular situation is bad and apt to get worse unless something is done about it, then aggressive action is likely to result—in the polling booth, in legislative chambers, in the town hall, or in the market place. Aroused public opinion becomes an irresistible force able to move even immovable objects.

In the face of aroused public, a suspected offender will do well to have mustered all facts of the matter in advance and make them generally understood. Too often too many people have tried to explain too little of their case too late. On the other hand, too often too little attention has been given to the important matter of rallying the potent force of public opinion in the support of unquestionably desirable community projects.

In the Pacific Northwest, people are especially sensitive about anything that affects their natural environment. They are beginning to experience, in many communities, the population pains long known to the East and metropolitan Midwest. With increasing frequency, they are becoming aware of their wastes. Although pollution problems are not yet comparable to those encountered in more heavily populated areas—nor apt to become so—people are becoming disturbed. Many of them realize that there is a problem and sense that it may become serious. But too often they do not really understand the problem itself. This is most serious. When community problems are understood, they are usually solved. Conversely, when they are not understood, they are usually bungled.

Public Relations in Education

Those who are interested in attaining the objective of clean streams and shorelines will recognize that they can learn to work more effectively in this area by studying the experiences of those who have been working to achieve other important community improvements over a long period of time. The experiences of those who have worked to provide better educational facilities

* Presented at the 25th Annual Meeting of the Pacific Northwest Sewage and Industrial Wastes Assn.; Spokane, Wash.; Sept. 25-27, 1958.

for the youth of the nation are well worth study from this point of view.

Scores of communities in the State of Washington annually hold levy and bond elections to make capital outlays and meet operating expenses. In 1953 a study of school election campaigns was made to determine their pattern of success or failure. In the 101 districts studied, it was found that one issue failed for every two that were successful. Hundreds of involved citizens in these districts were interviewed in an attempt to analyze causes for the outcome in each instance. The study resulted in the following conclusions being drawn:

1. Community groups must be kept informed throughout the year. It is unrealistic to gloss over long periods of no information, misinformation, or community unrest with several weeks of "sweet talk" campaigning, and expect to find general public support.

2. Districts which conducted maximum campaigns (campaigns where virtually every known means of informing the public were employed) stood better than four chances in five of gaining public acceptance. Conversely, districts in which minimum campaigns were conducted to inform voters had at least a 60 per cent chance for failure.

Public Relations in Pulp Industry

Examination of the public relations experiences of the pulp industry in the Pacific Northwest reveals a similar pattern. The first pulp mill was set up in Washington nearly a century ago and the industry has since grown to such an extent that this state now outstrips all other American states in pulp production, and all except four nations. Its employees annually earn $75 million in wages and salaries. Local governments derive $7 million from it each year in taxes. Products worth $450 million are annually shipped from its mills. Its operations daily require the use of millions of gallons of practically pure water which, after filtering and use, is reused and treated before being returned to local receiving waters. To increase protection of other uses to which local receiving waters are put, the industry has made extensive plant modifications and a quiet investment of millions in research. It has made improvements in process methods and practices, some of which were for years thought impossible or totally impractical, that have significantly reduced the loss of chemicals and organic matter in its effluents. The pulp industry has made much progress in this field. Its research assures even more.

While the above facts are generally known by those who are engaged in the field of industrial wastes disposal, they are not generally known by the public. The pulp industry has historically been reluctant to turn the spotlight on itself, even on its growing contributions to the local economy or on its achievements in both wood and water conservation. It elected to wait until its research scientists and engineers had found all, or at least more, of the water-quality control answers. Sincere purpose and logical reasoning notwithstanding, this proved to be a mistake for, while industry remained silent, others did not. The resulting publicity, while mostly motivated by honest concern and well-meaning intention, has often been grossly inaccurate, distorted, and sometimes damaging.

In Washington and Oregon nearly two years ago, the pulp industry set out in its public relations policy to rectify these shortcomings in public understanding. It formed the Northwest Pulp and Paper Association, through which it has not only coordinated research efforts on water quality control, but has also begun to talk. It has not talked especially about its importance to local economy or the number of people it steadily employs, but rather about such matters as chemical

treatment, the barging and the burning of its wastes, heat and chemical recovery, by-product research, and resource conservation and water quality control. By these means it hopes to establish its role for the first time in accurate context in the public's mind.

Public Relations Principles

In general, the solution to a community problem has three distinct phases:

1. Awareness of the problem; that is, seeing a need to do something.
2. Assessing the alternatives and determining a feasible solution.
3. Achieving public understanding that sparks intelligent action.

First, the need; second, the solution; third, the understanding.

Seattle's Disposal Problems

The city of Seattle has been going through these phases in recent years with respect to the disposal of domestic wastes in city and suburbs. Over a period of years, it became increasingly evident that it was giving insufficient attention to the treatment and dispersion of its domestic sewage. Raw, untreated sewage deposits accumulated in the river. Algae growth exploded. Swimming areas closed. Real estate developments slackened. Seattle rated sixth nationally on the "most polluted area" list. Phase one, "Seeing A Need To Do Something," had been realized.

Three years ago the Washington Pollution Control Commission proposed that the solution involved formation of a metropolitan sewer authority, extending over county and city boundaries. It was observed by the Commission that such a plan at that time probably sounded idealistic but that perhaps idealism was required to solve this important problem. The Commission further counseled that local people could help in the solution of the problems by making it a point to understand them and then to talk them over in their civic groups and with others in the area.

This was three years ago. Subsequently, city engineers and consulting engineers methodically assessed the situation. A solution was sought and found. Plans were drawn. Phase two, "Assessing The Alternatives And Determining A Feasible Solution," was achieved.

After a brief flurry of publicity describing engineers' recommendations, "The Metropolitan Plan," authorizing establishment of a council to engage in activities ranging from pollution control to comprehensive planning to mass transportation, was submitted to voters last March. This plan, frankly complex, was not thoroughly understood by voters in all affected areas and the voters rejected it.

But the plan itself was then simplified. Educational efforts continued. Information programs were accelerated by The Seattle-King County Municipal League, League of Women Voters, both major county political parties, a host of governmental and semi-governmental agencies, and others. Major daily newspapers participated and contributed much in terms of detailing the problem, explaining "The Plan," answering questions, and suggesting the consequences.

During the heat of a truly hot summer, another blow for understanding was struck when the Seattle-King County Health Department closed a number of sewage-saturated beaches, blacklisted a host of others, and described in graphic terms the high degree of contamination prevalent even in alleged "safe" swimming areas.

In September of 1958, general public understanding of the whole matter was recorded at the polls. Voters overwhelmingly agreed to launch "The Plan" aimed at cleaning up water and ground contamination in the greater Seattle area. Phase three, "Public Un-

derstanding That Sparks Intelligent Action," had been achieved.

Are Public Relations and Wastes Miscible?

Are public relations and wastes miscible? Are they capable of being mixed? Of course. As a matter of fact, the truth is that, if they are not mixed, the problems involved in dispersing the wastes are not so apt to be satisfactorily solved. For, in the case of municipal, county, and state agencies responsible for waste removal or waste control, it is made painfully aware at times that appropriation of adequate public funds usually comes only after public understanding has been achieved. And, in the case of private industry, there is also growing realization that, unless industry supplies the technical and economic facts on its waste dispersal activities and achievements, industry will be hurt. In considering the dispersing and disposing of both domestic and industrial wastes, one fact remains the same. These wastes cannot be hidden. No magician's wand can whisk them away and people must never be misled into thinking that they can.

Since this is so, the public must understand that it is so. There is no alternative, then, but to talk about these wastes: talk about the multiple beneficial uses of water, including proper and adequate waste dilution and dispersion; talk about the fact that states have determined regionally the multiplicity of water uses and standards to protect those uses; and talk about the monitoring programs which both regulatory agencies and dischargers themselves have designed to protect local receiving waters.

"Public Relations" is a term which is sometimes used loosely to describe a variety of activities which are the antithesis of the kind of public relations required to meet the needs of the present situation with respect to waste disposal. It should not be used to describe propaganda or "smart" publicity. Neither is it the right term for the case-building documentations, deliberately ignoring part of the facts, which have occasionally been used by public agencies to justify expanded budgets and authority. It is an equally poor term to employ in describing the slick campaigns built on half-truths which have sometimes been launched in desperation by private groups to prevent the imposition of justifiable corrective regulations. Public relations of the kind and character that are needed here are of the long-term, continuous type which grows out of the honest desire to provide people with the necessary facts which they need to have in order to govern themselves intelligently. It should also be a public relation program of sufficient stature to acknowledge past mistakes. Individual and corporate members of the community share in this kind of public relations responsibility, and when they face up to this responsibility squarely, waste problems will be disposed of constructively and permanently.

AN INVESTIGATION OF THE MECHANISMS OF CONTROLLED FILTRATION *

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Editor's Note—In FSIWA Manual of Practice No. 6, "Units of Expression for Wastes and Waste Treatment" (1958), the following trickling filter units are recommended:

Unit Replaced	*Conversion Factor*	*Recommended Unit*
Million gallons per acre per day	× 23	= Gallons per day per square foot
Gallons per 1,000 square feet per day	× 0.001	= Gallons per day per square foot
Pounds BOD per acre foot per day	× 0.023	= Pounds BOD per day per 1,000 cubic feet
Pounds BOD per cubic yard per day	× 37	= Pounds BOD per day per 1,000 cubic feet

These units are offered for those readers who wish to convert the author's units to the recommended units. The Journal has accepted the recommended units.

This investigation is an expansion of previous studies (1) of the fundamentals of controlled sewage filtration in which it was established that:

1. First section performance of controlled filters is comparable with the performance of high-rate filters and thereafter there are basic differences.
2. No upper limiting relationship of removal of the BOD to either organic load or hydraulic load is evident.
3. The controls of sewage application, air application, and temperature influence successful treatment at high rates and the provision of a favorable habitat for filter biota.
4. A combination of continuous and constant flow produce the best filter performance.
5. The filter loading ratio provides a simple basis for computing the filter size, since it is an expression of sewage strength in terms involving depth of filter, area of filter, quantity of sewage, and weight of BOD.

The present study has been directed to further investigations under a series of controlled conditions of sewage application, air flow, and temperature in an effort to establish:

1. Basic reasons for the efficiency of deep filter performance.
2. The nature of organisms living in the filter and their relationship, if any, to the progressive improvement of the waste within the filter.
3. The hydraulic and organic loading application limitations of the filter and the reasons for failure beyond the limits observed.
4. The theoretical differences be-

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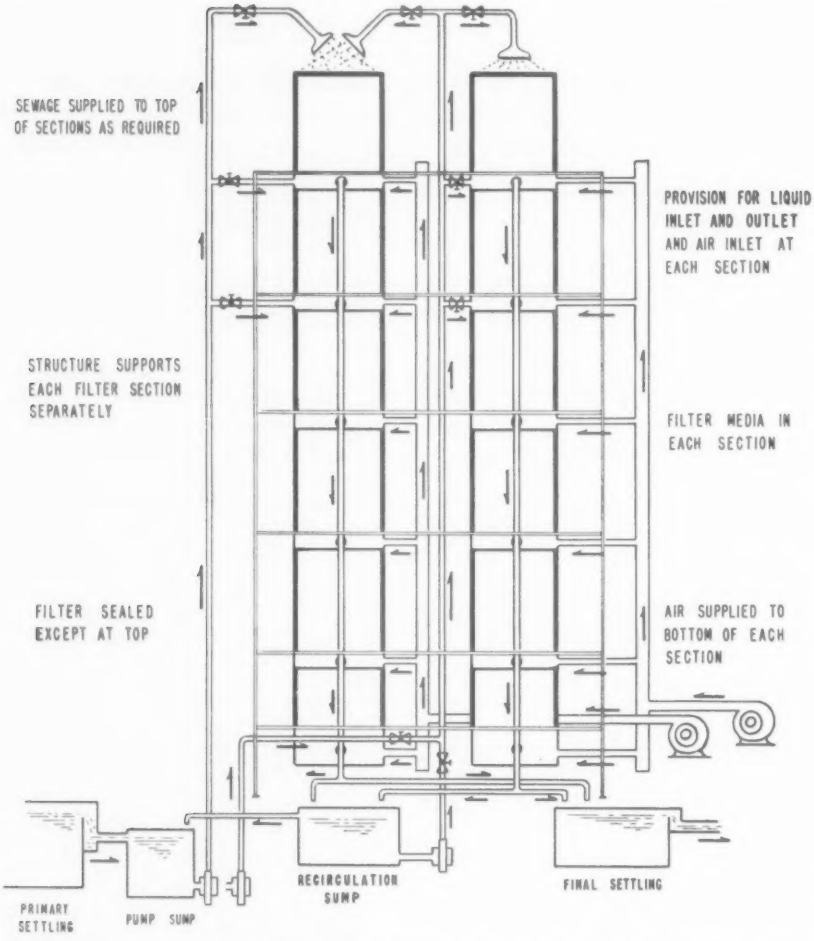
SEWAGE SUPPLIED TO TOP OF SECTIONS AS REQUIRED
PROVISION FOR LIQUID INLET AND OUTLET AND AIR INLET AT EACH SECTION
STRUCTURE SUPPORTS EACH FILTER SECTION SEPARATELY
FILTER MEDIA IN EACH SECTION
FILTER SEALED EXCEPT AT TOP
AIR SUPPLIED TO BOTTOM OF EACH SECTION
RECIRCULATION SUMP
FINAL SETTLING
PRIMARY SETTLING
PUMP SUMP

FIGURE 1.—Schematic diagram of equipment used in two-filter experimental unit.

tween the behavior of reported existing filters and a controlled deep filter as observed in the proposed investigations.

5. Formulations expressing the behavior of controlled deep filters.

The material presented here may be considered as a progress report on filtration through deep filters.

Description of Filter

The deep filter unit is composed of six sections, each having a depth of 3 ft and a diameter of 12 in. It is built as a single column and is a closed unit from top to bottom, except that access is provided under controlled conditions for admission of sewage and air. The unit has been so constructed that settled sewage can be applied to the top of Sections 1, 2, and 3. Room air is admitted to the bottom of each section in predetermined and controlled amount. Temperatures were approximately 70 to 75°F.

TABLE I.—Test Conditions for Eight Runs with First Filter*

Run	Duration (days)	Flow Rate (mgd/acre)	Sewage Appl. Rate (gpm)	Air Appl. Rate (cfm)	Distribution of Air
1–1	22	159.8	2.0	2.0	Uniform all sections
1–2	48	159.8	2.0	2.0	Increased to first 2 sections, reduced to others
1–3	22	239.6	3.0	3.0	26 and 35 per cent to first and second sections, less than 10 per cent to each of others
1–4	34	199.7	2.5	2.5–2.7	To each of the six sections in per cent as follows: 22.2, 37, 11.1, 11.1, and 7.5
1–5	37	159.8	2.0	2.0	To each of the six sections in per cent as follows: 29, 30, 12.5 to each of 3 through 6
1–6	19	159.8	2.0†	2.0	Same as Run 5
1–7	9	159.8	2.0	2.0	Redistributed in Sections 3, 4, and 5
1–8	10	159.8	2.0	4.0	To each of the six sections in per cent as follows: 32.5, 17.9, and 12.5 to each of 3 through 6
1–9	365‡	159.8	2.0	4.0	Same as Run 8

* Sewage temperature ranged from 16 to 29°C, and averaged 19.6°C.
† Sewage flow intermittent and supplemented many times with water in order to keep the filter wet.
‡ Approximately.

A second column identical to the first permits great flexibility in the experimental work. Settled sewage may be applied directly to any one of the upper three sections of either column. Likewise, effluent from the first filter may be applied to any one of the upper three sections of the second filter. Effluent from either filter can be returned to the top of the first filter independent of the settled sewage application. Effluent from either column can be mixed with settled sewage and the mixture applied in the same manner as the settled sewage to either column. The diagrammatic layout of the system is shown in Figure 1.

The several sections of the filter are filled with stone of nominal 2-in. diameter. Each section is independently supported on a plate and the load is transferred to columns and thence to the foundation. While the liquid flow is continuously downward there are spaces between the stone bed at each section. This arrangement makes it easier to admit sewage and air to the column. It is also possible to study the filter liquid delivered from each section as a discreet portion of the total column. The bottom of the filter is trapped so that all air admitted must pass upward and out the top of the filter column.

Test Runs

Runs 1–1 through 1–8 were carried out on the first filter. Test specifications are shown in Table I. Filter conditioning was accomplished in Run 1–1. Run 1–9 was carried out for the longer period.

The second filter was placed in operation in January 1958. During these runs the relationship of air flow to applied sewage was maintained at 2 cfm/gal. Identical sewage was applied to both filters so that results from Run 1–9 could be used as a base line for examining changes occurring because of the variations on the second filter.

The variations among Runs 2–1 through 2–5 are shown in Table II.

In October 1958, the pumping and screening arrangement was changed to obtain a stronger sewage. The operating conditions for Runs 1–10 and 2–6 remained unchanged from Runs 1–9 and 2–5, except for the change in sew-

TABLE II.—Test Conditions for Five Runs with the Second Filter

Run	Duration (days)	Flow Rate (mgd/acre)	Sewage Appl. Rate (gpm)	Air Appl. Rate (cfm)	Sewage Temp. Range (°C)
2–1	56	79.9	1	2	15–20
2–2	22	159.8	2	4	15–21
2–3	38	199.7	2.5	5	13–21
2–4	52	239.6	3.0	6	18–22
2–5	73	279.5	3.5	7	21–30

age characteristics. The sewage temperature range for November-December 1958 was 16 to 24°C.

Study of filter biota started in the spring of 1957, was expanded in the fall, and is continuing through 1958–59.

A plastic bead filter comprising 3/16-diam × ¼-in. pellets was set up in a 1½-in. diameter column, 2.5-ft deep in August 1957. This was a separate filter used to study media and effects on sedimentation. Filter effluent was trapped in a small holding tank having about three minutes detention and the filter effluent was pumped from the tank to the bead filter at the same flow rate as that of the main filter (159.8 mgd/acre). The plastic tended to float and also seemed to erode, and in November 1957, the plastic bed was replaced with a bed of ¼-in. diameter gravel. Later this filter was changed to a 3-in. diameter column with 2-in. diameter rock.

Laboratory analyses follow a weekly schedule except for interruptions due to week ends, holidays, repair work, and temporary suspension of filter operations. The basic schedule is shown in Table III.

Discussion of Results

Top and Step Feeding

Much of the first year was given to the exploration of conditions which might be limiting. In previous work (1) the flow to top of Section 1 was carried to 199.8 mgd/acre on one run lasting 10 days, during which the average efficiency of BOD removal was 76 per cent with an organic loading of 6,830 lb/day/acre-ft. The filter had been operating on a three-stage application at the same total flow rate prior to this run, so that the only variation was point of application of sewage.

During 1956–57 following the ripening period, the top loading was boosted to 239.6 mgd/acre (Run 1–3). Within a week efficiency of BOD removal began to drop. Back pressure began to develop in the filter and over a 22-day span it became obvious that with the volume of air that could be put into the filter under the existing conditions, it would be impossible to carry that rate of flow on a top feeding basis.

The flow was reduced to 199.7 mgd/acre (Run 1–4) with 2.5 to 2.7 cfm of air and no recovery was observed. Run 1–4 was terminated when on two successive profiles zero dissolved oxygen conditions throughout the column were recorded. These conditions continued

TABLE III.—Sampling and Analyses Schedule for Test Program

Sampling Frequency	Sampling Point	Analyses
Daily	Raw sewage Settled sewage Filter effluent	DO, BOD, pH, MO alkalinity, SS
Daily	Filter effluent	Settleable solids
Weekly	Filter profile by sections	DO, BOD, pH, MO alkalinity, TS, SS, VS, NO_2, NO_3, and qualitative microscopic examination
Occasional	Filter effluent	Relative stability
Special	Filter effluent	Hourly samples for settleable solids
	Secondary filter effluent Filter sectional profile	Quantitative and group identification of biota

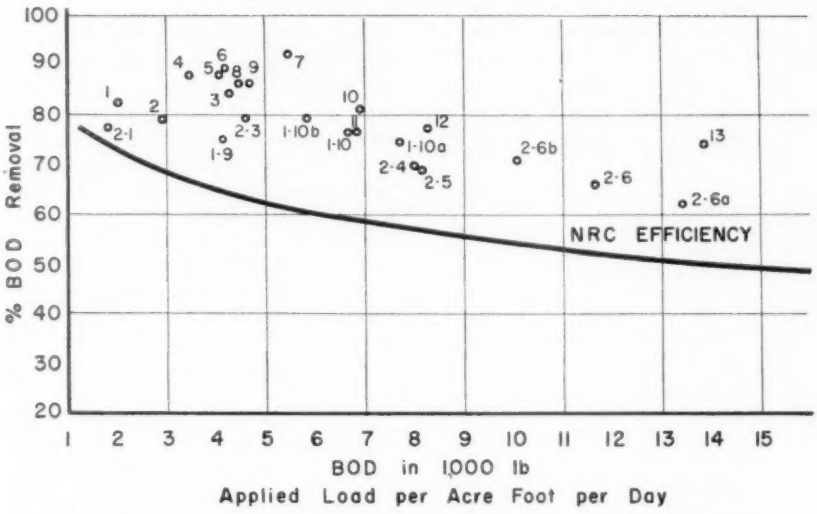

FIGURE 2.—Comparison of filter performance with data from NRC Report.

for another 10 days after the flow had been reduced to 159.7 mgd/acre. Then a slow recovery followed. However, it was more than 30 days before the filter efficiency approached that found in the previous studies.

Table IV summarizes the DO, filter loading, and BOD removal for Runs 1–7, 1–8, 1–9, 1–10a, and 1–10b on the first filter, and Runs 2–1 through 2–6 on the second filter. Runs 1–92–1 through 1–92–5 were portions of Run 1–9 coinciding with runs of second filter; *i.e.*, 1–9 for period of 2–1 is 1–92–1. It has been observed that the hydraulic flow rate was not the limiting factor. Rather, the studies now suggest strongly that the relationship between oxygen supply and BOD loading is of greater importance. A visual observation reveals that BOD removal is at about the same efficiency with the same loading regardless of whether the loading is accomplished by a higher flow rate of weaker sewage or a lower flow rate of stronger sewage.

Even though sharply defined limits in the ability of the filter to remove BOD have been sought, they have not yet been found. The results to date do not justify a conclusion that there is even a well-defined curve of removal efficiency with respect to loading. Figure 2 shows results of a series of 13 runs from earlier studies (1) together with results of runs on both filters in the present series. Runs 1 through 6 of the early work were top feeding operations. Runs 7 through 13 involved step feeding of settled sewage. Run 1–9 indicates BOD removal with all types of flow conditions including continuous application of sewage, continuous application either with sewage or water, and sometimes intermittent operation due to pump stoppage.

The runs of the second filter, shown as 2–1 through 2–6 produced the BOD loading both by increase in flow rate and increase in applied BOD. There is no instance among the averages of these several runs in which efficiencies lower than that shown by the NRC efficiency curve (2) are demonstrated. It would appear further that there are advantages in the step application of sewage; however, these advantages have not been explored in the present

TABLE IV.—Summary of BOD and DO Results

Run	BOD Loading (lb/day/acre-ft)	Sewage Appl. Rate (mgd/acre)	Ratio of Organic to Hydraulic Loadings (lb/mil gal)	Effluent DO (mg/l)	BOD Removal by Filter (per cent)
1–7	4,200	159.8	473	4.1	67.2
1–8	3,820	159.8	430	4.9	76.1
1–9	4,100	159.8	462	4.6	75.0
1–10a	7,660	159.8	864	4.0	74.0
1–10b	5,740	159.8	647	4.8	79.2
1–92–1	3,610	159.8	407	5.4	72.5
1–92–2	4,190	159.8	472	4.7	67.2
1–92–3	3,700	159.8	417	5.3	77.0
1–92–4	5,340	159.8	602	4.3	70.8
1–92–5	4,630	159.8	522	4.0	79.6
2–1	1,790	79.9	404	5.7	76.8
2–2	4,110	159.8	463	4.8	75.5
2–3	4,620	199.7	416	4.8	79.2
2–4	8,000	239.6	602	3.8	69.2
2–5	8,110	279.5	522	3.0	68.5
2–6a	13,400	279.5	863	3.0	62.0
2–6b	10,050	279.5	647	2.6	70.7

research. Until a definite point of determination of filter efficiency with top feeding has been found it remains a matter of speculation as to whether step application provides a convenient and useful operating tool to absorb changes in flow rate or whether it is truly a means of loading the filter with BOD beyond that possible by top feeding alone. In Figure 2 the relationship between Point 13 (3-step feeding) and Point 2–6b suggests an advantage in BOD removal efficiency at higher BOD loadings by step application, whereas the relationship between Points 10, 11, 12 and 1–10a, 1–10b, 2–4, and 2–5, does not indicate any great difference in efficiency at lower loadings. It should be remembered that these controlled filter loadings range from 8 to 20 times the recommended loading for standard trickling filters without recirculation (3).

A direct comparison of concurrent runs on both filters under the different loading conditions demonstrates further the relationship of BOD loading to efficiency of removal. The results of these comparative runs are shown in Table V.

At half the loading Filter 2 is but slightly better than Filter 1. At equal loading Filter 2 performance is slightly better. Other comparisons are evident in the table. However, it is difficult to assess the actual significance of the apparent differences in efficiency because some may be due to the errors inherent in biological sampling.

Sectional Performance

Filter behavior is perhaps better understood by reference to sectional removal results. Table VI indicates the effectiveness of each section under different conditions of loading. For each section the per cent BOD removal is given for its load rather than as a fraction of the original load. The comparison of Filter 1 and Filter 2 sectional removals during Runs 2–6a and

TABLE V.—Comparison of BOD Removal in Filter 1 and Filter 2

Run	Filter Loading (lb/day/acre-ft)		Ratio 2:1	BOD Removal					
				Filter (per cent)		Ratio 2:1	Plant Efficiency (per cent)		Ratio 2:1
	1	2		1	2		1	2	
2–1	3,610	1,790	.50	72.5	76.8	1.06	83.5	86.1	1.03
2–2	4,190	4,110	.98	67.2	75.5	1.12	77.4	83.5	1.08
2–3	3,700	4,580	1.24	77.0	79.2	1.03	86.6	87.9	1.02
2–4	5,340	8,000	1.50	70.8	69.2	0.98	82.1	81.0	0.99
2–5	4,630	8,110	1.75	79.6	68.5	0.86	87.9	81.4	0.93
2–6a	7,660	13,400	1.75	74.0	62.0	0.84	84.9	78.0	0.92
2–6b	5,740	10,050	1.75	79.2	70.7	0.89	90.7	86.8	0.96

TABLE VI.—Sectional BOD Removal

Section	BOD Removal by Section During Run (per cent)									Run 2-6a,b Ratio 2:1
	1-7	1-8	1-9	1-10a,b	2-1	2-2	2-3	2-4	2-6a,b	
1	11.4	34.7	34.3	28.3	58.6	23.7	32.0	16.7	23.5	0.83
2	19.6	26.7	26.7	18.2	36.3	21.0	18.5	19.5	14.3	0.79
3	24.4	18.2	29.6	24.6	18.3	37.5	42.4	23.4	19.4	0.79
4	15.7	31.1	14.8	20.8	24.3	19.4	12.0	25.9	17.3	0.83
5	12.6	19.4	18.1	24.2	16.7	19.7	16.9	17.1	13.6	0.56
6	14.4	8.0	12.4	18.1	7.7	9.5	15.3	19.3	10.4	0.57

2–6b and 1–10a and 1–10b suggests that under the higher loadings each section of Filter 2 was less efficient than its counterpart in Filter 1, and that the performance becomes less efficient in the lower sections. This phenomenon is undoubtedly related to the dissolved oxygen content. It will be observed from Table IV that the DO in the effluent of Filter 2 during Runs 2–6a and 2–6b is decidedly lower than that in Filter 1 effluent. This relationship is still under exploration in these studies.

Dissolved Oxygen

In a new series of experiments the air will be increased to hold DO at 4.0 mg/l or more, and an attempt will be made to counterbalance demand in the upper sections by increasing the air supply in those sections. Table VII demonstrates the dissolved oxygen profile through the filters for several runs. Between Run 2–1 with a light loading and Run 2–6a with an extremely heavy loading there is an obvious difference in the DO content section by section. However, these differences are not reflected too clearly, if at all, in the intermediate loadings. However, it can be said that there is a tendency to reduce oxygen content as the loading increases and that the upper sections seem to be more seriously affected by the higher loadings.

There is a possibility that the variations are related to the biological growth. It is a matter of conjecture at present as to which is a causative and which is a resultant of filter conditions. Table VIII presents data obtained during 1957 with respect to the DO in sections.

Microscopic Examination

Table IX demonstrates the microbiota found by microscopic examina-

TABLE VII.—DO Profiles

Run	Avg Loading (lb/day/acre-ft)	Top of Section Average DO (mg/l)						
		1	2	3	4	5	6	Effl.
1–9	3,540	0	0.33	1.18	2.94	4.05	4.70	4.58
1–92–1	3,340	0	0.66	1.81	3.58	4.52	4.98	5.05
1–92–2	4,470	0	0.50	0.73	2.50	3.83	4.50	4.27
1–92–3	3,940	0	0.30	1.83	3.60	4.50	4.90	4.73
1–92–4	5,010	0	0.97	1.57	2.70	3.97	4.47	3.97
1–10a	7,670	0	0	0.30	1.42	2.02	3.15	3.48
2–1	1,770	0	1.22	1.57	4.34	5.13	5.76	5.54
2–2	4,470	0	0.60	1.72	2.50	3.60	4.13	4.18
2–3	4,930	0	0.20	2.13	3.67	3.83	4.43	3.77
2–4	7,510	0	0.80	1.37	2.00	2.47	3.30	3.23
2–6a	13,420	0	0	0	0	0.20	1.32	1.62

TABLE VIII. Microorganism Studies

Date DO Profile (1957)	Dissolved Oxygen (mg/l)						
	Infl.	Section					
		1	2	3	4	5	6
2/20	0.0	2.1	2.1*†	2.7*	2.8	3.1	3.5*†
3/6	0.7	2.2	2.7	2.7	3.5*	3.6	3.8†
3/12	0.0	1.9	2.1	2.0	2.1	2.4*	2.1*
3/19	0.0	2.4	2.5	3.2	3.6*	4.0	4.2
3/29	0.0	0.0	0.1	1.3	1.9	2.3†	2.8
4/2	1.7	1.9†	2.4†	2.8†	3.9†	4.3†	4.4*†
4/23	0.0	2.3	2.6*†	3.6	4.1†	4.6*	4.3
4/26	0.0	1.2*	1.7*†	2.1*†	2.7*†	3.2*	3.2*

* Conditions in this section apparently less favorable than usual for growth of flagellates.

† Conditions in this section apparently less favorable than usual for growth of free-swimming ciliates.

tion of the filter by section on those separate days. Table X shows a comparison of microbiota found in Filters 1 and 2 operating at different loadings by virtue of the difference in flow rate; Filter 1 running at 159.9 mgd/acre and Filter 2 at 279.5 mgd/acre. The settled sewage applied to each filter is taken from the same sump suction. On this particular profile the loadings were 4,150 and 7,260 lb/day/acre-ft, and BOD removals were 82.1 and 76.8 per cent. The performance of the secondary filter following Filter 1 on this date was particularly noteworthy, removing two-thirds of the BOD applied to it and bringing the over-all Filter 1 and secondary filter efficiency to 95.9 per cent BOD removal.

It is noted that stalked ciliates appear in every section of both filters; however, these are predominant in Filter 1, sections 3 and 6, in the secondary filter, and in Filter 2 in section 6. Filter biota studies were made in 1957 and the early part of 1958 with attention given to the protozoa.

Protozoa Discussion

The protozoa recorded for Filter 1 are types normally expected from such environments and include a number of the forms listed by Lackey (3) for sprinkling filter beds. Ciliates have been predominant. Free-swimmers (e.g., *Paramecium, Colpidium, Chilodonella, Colpoda*) exceeded the stalked ciliates (peritrichs) from February through early July 1957. During July, stalked ciliates became about as numerous as free-swimmers and, from mid-August through January 1958, have generally been the dominant types.

Other groups of protozoa have been represented by small flagellates (mostly *Bodo* or related genera), occasional euglenoid flagellates, small amoebae, and shelled rhizopods (e.g., *Arcella, Difflugia*).

Free-swimming ciliates have shown erratic fluctuations during the year. With occasional exceptions, especially in Section 1, the patterns have been fairly similar throughout the filters, suggesting that, in most cases, factors affecting the number of free-swimmers may be common to all six sections.

Although stalked ciliates have shown somewhat comparable fluctuations, their populations tend to vary independently of the free-swimmers. Also, in Sections 4 to 6, populations of stalked ciliates have remained fairly stable in records for the period, December 6, 1957 to February 12, 1958.

The fluctuations in ciliates have shown no clear correlation with DO readings for the various sections. However, the period of stalked-ciliate dominance more or less coincides with a period of relatively high DO levels. It is believed that pH changes within the filter are not significantly involved in the ciliate fluctuations. Any other factors of possible significance probably would include the immediately available food supply (total food, or possibly concentrations of limiting factors such as vitamins).

All ciliates reported feed primarily on bacteria under natural conditions. In the laboratory, several types grow well in non-nutrient fluids containing

TABLE IX.—Quantitative Identification of Microbiota Found on Examination of Each Section of Experimental Filter

Microbiota	Sample Location						
	Top of Section						Effl.
	1	2	3	4	5	6	
(*a*) Mar. 12, 1957							
Zooglea	Abundant	Abundant	Abundant	Abundant	Abundant*	Abundant	Yes
Worms	Very numerous	Few	Few	Few	Few	Few	Yes
Flagellates	Numerous	Few	Few	Few	None	None	None
Filamentous bacteria	Moderate	Few	Few	Few	None	Few	Moderate
Free-swimming ciliates	Very few	Moderate	Numerous	Very numerous	Very numerous	Numerous	Very numerous
Stalked ciliates	None	1	Few†	Few‡	None	Few†	None
Suctoria	1	None	None	None	None	None	None
Rotifers	None	None	None	None	Very few	None	None
Amoeba	None	None	None	None	None	None	None
(*b*) Mar. 19, 1957							
Zooglea	Abundant	Abundant*	Abundant*	Abundant*	Abundant	Abundant	Abundant§
Worms	Moderate	Numerous	Numerous	Numerous	Moderate	Numerous	Moderate
Flagellates	Moderate	Moderate	Moderate	None	Moderate	Moderate	None
Filamentous bacteria	None	None	Moderate	None	None	None	None
Free-swimming ciliates	Moderate	Very numerous	Numerous	Numerous	Numerous	Very numerous	Very numerous
Stalked ciliates	Few†	None	None	Few	None	None	None
Suctoria	None	None	None	None	None	None	None
Rotifers	None	1	None	Few	Few	1 or 2	None
Amoeba	None	None	None	Few	None	None	None
(*c*) Apr. 2, 1957							
Zooglea	Abundant	Abundant	Abundant	Abundant	Abundant	Abundant	Abundant
Worms	Few	Few	Few	Few	Moderate	Few	Few
Flagellates	Few	Few	Few	Few	Few	None	Moderate
Filamentous bacteria	None	None	None	Moderate	Moderate	Moderate	None
Free-swimming ciliates	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Stalked ciliates	Few	None	None	None	None	Few	None
Suctoria	None	None	None	None	None	None	None
Rotifers	None	None	Moderate	None	Moderate	Few	None
Amoeba	None	Few	None	Few	None	None	None

* Mainly rhamose. † Mainly inactive. ‡ Active. § Rapidly growing.

one species of bacteria. Bacteria are also an important food source for most of the other protozoa seen occasionally or frequently. Accordingly, the ability to digest bacteria (and probably other small microorganisms) is characteristic of this protozoan fauna. In the laboratory, digestion of proteins, starches, and cellulose has been reported for several of the common types.

Even if bacteria were the only food used by these protozoa, any reduction in bacterial concentrations probably could not be great enough to impair operation of the filter. Laboratory experience of various workers suggests that, in a rich medium, bacteria tend to multiply about as rapidly as they can be eaten by herbivorous protozoa.

In addition to microorganisms, dissolved organic materials (cleavage products of proteins, carbohydrates, and lipids) probably are used by all of the protozoa observed. For certain types (*Colpidium, Colpoda, Paramecium, Amoeba*), there is conclusive evidence based on growth in pure cultures in nonparticulate media.

Ammonia is the most abundant nitrogenous waste for several of the recorded types as well as for various related protozoa not observed in the filter. Ammonia may be produced in quantities. For example, in pure cul-

TABLE X.—Quantitative Identification of Microbiota From Two Experimental Filters Operated at Different Loadings on the Same Day

Microbiota	Sample Location								
	Top of Section						Individual Filter Effl.	Sludge from Filter 1 Effluent Reservoir*	Secondary Filter
	1	2	3	4	5	6			
(*a*) Filter 1†; BOD Loading, 4,150 lb/day/acre-ft; Aug. 1, 1958									
Zooglea	Moderate	Few	Few	Few	Few	Few	Moderate	None	Few
Worms	Moderate	Moderate	Few	Few	Few	Few	None	Very numerous‡	Few
Fungi	Moderate	Moderate	Few	Few	Moderate	Moderate	Moderate	Moderate	Few
Stalked ciliates	Few	Moderate	Very numerous	Moderate	Moderate	Numerous	Moderate	Numerous	Numerous
Free-swimming ciliates	Few	None	None	None	Occasional	Few	Occasional	Moderate	Moderate
Rotifers	Few	Occasional	Moderate	Occasional	Moderate	Moderate	Moderate	None	Moderate
(*b*) Filter 2§; BOD Loading, 7,260 lb/day/acre-ft; Aug. 1, 1958									
Zooglea	Moderate	Moderate	Few	Moderate	Few	Few	Moderate	—	—
Worms	None	Few	None	Few	Few	Few	Few	—	—
Fungi	Moderate	Few	Very numerous	Few	None	Few	None	—	—
Stalked ciliates	Occasional	Few	Few	Moderate	Moderate	Numerous	Moderate	—	—
Free-swimming ciliates	Occasional	Numerous	Few	Occasional	Few	None	Few	—	—
Rotifers	None	None	None	Occasional	Few	Numerous	Numerous	—	—
Flagellates	None	Few	Few	None	Few	Few	—	—	—

* Much dead material evident.
† DO as follows: top of Section 1, 0; filter effluent, 4.2 mg/l; final effluent, 4.3 mg/l.
‡ Macroscopically.
§ DO as follows: top of Section 1, 0; filter effluent, 3.4 mg/l.

tures of one ciliate species, ammonia-N has shown increases of 500 to 600 per cent, up to levels of 40 to 50 mg/l N. It might be expected that, during operation of the filter, the protozoan fauna would produce an appreciable amount of ammonia. Any fluctuations in the concentration of ammonia might show some correlation with density of the protozoan population.

Comparison of fluctuations in total ciliates (free-swimming and stalked) and in nitrite levels suggests a possible correlation. A nitrite peak on August 1, 1957, followed a rise in ciliate population. High nitrite levels during August 26 to September 12, coincided with high ciliate densities in Sections 3 to 6. Also, high ciliate densities in Sections 3 to 6 preceded the rise in nitrite beginning in early November. Whether or not this apparent correlation is real, some such relationship might be expected in the sequence: increase in protozoan population—increase in production of ammonia—increase in nitrite level through bacterial activity.

The groups arbitrarily selected for study were:

1. Zoogleal masses of bacteria.
2. Sessile ciliates, such as *Carchesium, Vorticella, Epistylis.*
3. Motile ciliates, such as *Colpodium, Paramecia.*
4. Larger types of flagellates, such as *Euglena.*
5. Small types of flagellates, such as *Chlamydomonas,* Chrysomonads.
6. Nematodes or Annelids.

Table XI indicates quantitative determinations for three examinations of filter effluent liquor.

TABLE XI.—Quantitative Examinations of Filter Effluent for Organism Groups

Organism Grouping	Count per ml		
	11/20/57	11/27/57	12/12/57
Zoogleal masses	4.35×10^3	4.0×10^3	4.5×10^3
Sessile ciliates	1.6×10^3	1×10^3	3.3×10^2
Motile ciliates	1.3×10^3	1.75×10^3	3.3×10^2
Nematodes	1.6×10^2	5×10^2	—
Small flagellates	10×10^3	11×10^3	12.7×10^3
Large flagellates	None	—	5×10^2
Rotifers	2.5×10^2	—	—
Fungal hyphae	—	—	1.7×10^2

Summary and Conclusions

This report of progress provides some information on filter behavior under a variety of loading conditions. It does not presume to answer a number of the questions which are scheduled for investigation in these studies.

It has been demonstrated in both present and previous studies that the behavior of the filter through the first section follows the theory of Velz (4) reasonably well, but thereafter there are essential differences. The so-called non-removable BOD can be removed with depth, and also there apparently is a striking removal in a secondary filter that is comparable in efficiency to removals at the beginning of filtration; however, the secondary filter is treating a BOD of the class referred to as non-removable.

There apparently are advantages in maintaining hydraulic flow rates at levels which keep filter sludge washed clear. The companion filters give comparable performance with not greatly different BOD removal, even though the organic loading on one is 1¾ times greater than the other. There is as yet no clear indication that a maximal condition of top loading has been reached even though there is some demonstration of a drop in efficiency at the higher loadings when oxygen levels are not maintained. It has been shown throughout the studies that better results follow continuous flow and that intermittent flows cause sloughing. This may be due to hydraulic disturbance, a change in the food balance in the filter, or shifting of dissolved oxygen levels, or all in combination.

Throughout the investigation the filter has given consistent average results better than those predicted by projection of the NRC curve. A year's continuous operation failed to produce a period of inefficiency.

While temperature undoubtedly has some influence, it has not as yet been demonstrated as critical. The filter has operated between 13 and 30°C.

By controlling the initial food supply for filter biota through manipulation of flow rate and by keeping an aerobic habitat for filter biota through manipulation of a positive air supply it has been possible to treat sewage satisfactorily on the experimental filter units by passing it once through a deep filter at organic loading rates up to 13,400 lb/day/acre-ft. On the present filters, that rate represents a surface loading of 241,000 lb/day/acre, or 5.5 lb/day/sq ft. The hydraulic rate used to date has reached 279.5 mgd/acre, or 35.7 fph.

Acknowledgments

This study was supported by a research grant from the National Institutes of Health, U. S. Public Health Service.

Routine operations and the daily laboratory work have been performed by or under the supervision of John Bevan. Microscopic analyses have been done by Dr. Gail P. Edwards. Special studies on microorganisms have been done by Dr. Richard Hall and Dr. Bernard Newman. Professor Gerald Palevsky and Mr. Lawrence Slote have assisted the author and project director in many ways. The contributions made by all participants on this project are acknowledged.

References

1. Ingram, W. T., "An Approach to the Design of Trickling Filters." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **82**, SA3, 999 (1956).
2. National Research Council Subcommittee, "Sewage Treatment at Military Installations." *Sewage Works Jour.*, **18**, 5, 794 (Sept. 1946).
3. Lackey, J. B., "Studies of the Fauna of Imhoff Tanks and Sprinkling Beds." 3rd Annual Report, Sewage Substation, Bull. 403, New Jersey Agric. Exp. Sta., New Brunswick, N. J. (1924).
4. Velz, C. J., "A Basic Law for the Performance of Biological Filters." *Sewage Works Jour.*, **20**, 4, 607 (July 1948).

PHS TRAINING COURSES

Several courses are being offered at the Public Health Service's Robert A. Taft Sanitary Engineering Center in the near future. These courses are available to those interested in the specific subjects offered. No tuition fee is required. Applications should be addressed to the Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or to a PHS Regional Office Director.

The list of courses is as follows:

Oct. 5–16	Basic Radiological Health
Oct. 19–23	Radionuclide Protection
Oct. 26–Nov. 6	Plankton Identification and Control
Nov. 9–20	Basic Radiological Health
Nov. 30–Dec. 11	Medical Aspects of Radiological Health
Nov. 30–Dec. 11	Chemical Analyses for Water Quality

DETERMINING SUSPENDED SOLIDS USING A SPECTROPHOTOMETER *

By Daniel Krawczyk and Norbert Gonglewski

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According to "Standard Methods," the determination of suspended solids involves the deposition of suspended material on a mat of asbestos fiber (1). The over-all time needed to complete such an analysis exceeds one hour. Normal routine in a treatment plant laboratory may require that four to six such determinations be made daily. Moreover, if the laboratory control program is expanded and greater numbers of suspended solids analyses are required in a minimum amount of time, the Gooch method has serious handicaps because more extensive facilities will be required.

The Buffalo Sewer Authority laboratory was confronted with the problem of conducting 20 to 30 suspended solids determinations per day when a study of sedimentation tank efficiencies was planned. Because facilities were limited, some samples had to be kept under refrigeration and analyses conducted the following day. Most probably, results would have been more satisfactory if all the laboratory work could have been completed on the day the samples were collected.

In view of the disadvantages of the Gooch method, an investigation was started to find a more rapid method of analysis. In 1935 Holmes (2) reported on a method for the determination of suspended solids using a colorimetric procedure without resorting to filters. A nephelometric system (3) showed some promise but colors inherent in various sewages eliminated this possibility from further consideration.

Filter Photometer

Particle Size

An attempt was made to measure suspended solids using a filter photometer with a variety of cells and in the first group of experiments it was found that particle size influenced the deflections of galvanometer needle. However, Holmes (2) using a colloid mill overcame the problem of non-uniform particle sizes and further investigation at Buffalo revealed that utilization of a blender would bring about uniform particle sizes.

A simple test was carried out to measure in some degree the uniformity of particle size of the blended sewage. From a gallon of raw sewage two 1-l samples were taken. One sample was blended and poured into an Imhoff cone, then the other sample (unblended) was poured into a second Imhoff cone and the respective settling rates were observed. The results from one such test are given in Table I. Repeated

TABLE I.—Settling Time of Settleable Solids

Settling Time (min)	Settleable Solids	
	Unblended Sewage	Blended Sewage
5	1.5	0
10	1.6	0
15	2.0	0
30	2.2	0
45	2.5	0
60	2.5	2.7
75	2.6	2.7
90	2.7	2.7

* Presented at the Spring Meeting, New York Sewage and Industrial Wastes Assn.; Liberty, N. Y.; May 26–27, 1958.

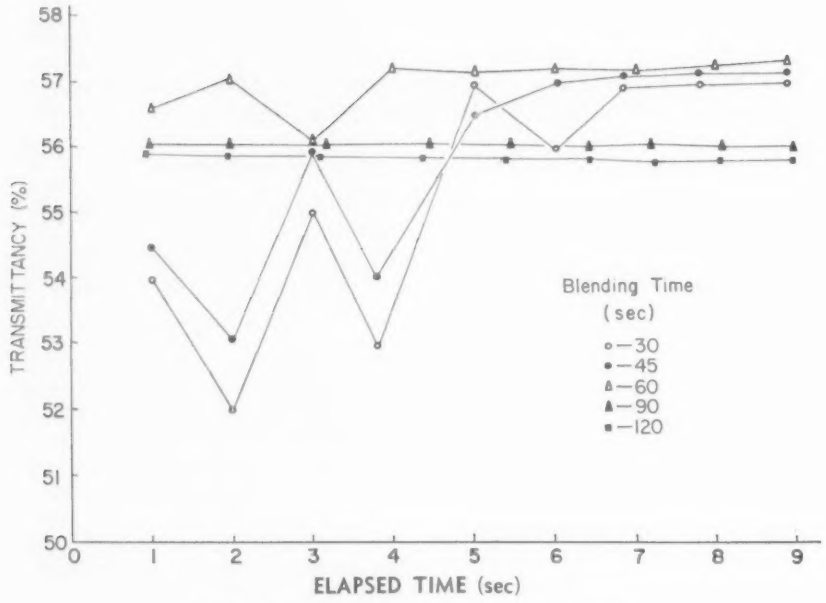

FIGURE 1.—Effect of blending on transmittancy.

tests demonstrated that solids from the blended sewage settled in a "clump" whereas solids from the unblended sample settled at varying rates. These observations show that blending produces a more uniform particle size, for according to Stokes' law, particles of the same size and the same density will settle with a constant velocity.

Samples of raw sewage were blended for various periods of time and their transmittancy was read at 1-sec intervals. These data are shown in Figure 1 and the results indicate that uniform particle sizes were obtained after 90 sec of blending.

BOD

After reaching this point, information was sought on possible biochemical changes that may be caused by blending. This was done by comparing the BOD values of blended and unblended sewage samples. The results from these examinations are given in Table II. As a precaution during blending, the blender top was covered to minimize the absorption of oxygen.

Project Abandoned

Continued studies with the filter photometer revealed that no other problems were encountered which could be attributed to variations in particle size; however, inherent color caused serious troubles. Efforts to solve the color

TABLE II.—Five-Day BOD of Blended and Unblended Sewage Samples

Unblended BOD (mg/l)	Blended BOD (mg/l)
83	94
76	91
107	100
109	107
113	109
114	119
116	118
126	130
132	120
145	140
150	135
250	225
297	294

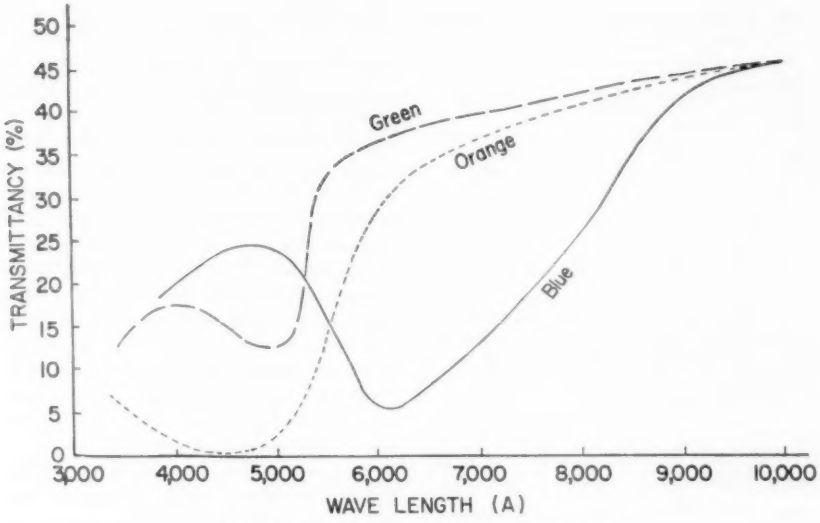

FIGURE 2.—Effect of color on transmittancy.

problem with a suitable filter arrangement were unsuccessful and the experimental studies were suspended.

Spectrophotometer

After purchase of a spectrophotometer, preparations were made to resume the search for a quick test for suspended solids. With this instrument, wave lengths of 7,000 to 10,000 A could be used and colors that might be encountered in sewage should cause no interference at these higher values. Figure 2 shows the effect of color on transmittancy at various wave lengths. The transmittancies of all three colored sewage samples intersect at about 9,000 A and continue together thereafter, indicating that color would have only a negligible effect above 9,000 A. Listed in Table III are some common colored solutions and for each is shown the wave length for minimum transmittancy as well as the maximum transmittancy at 10,000 A.

TABLE III.—Colorimetric Characteristics of Common Colored Solutions

0.01% Solution	Wave Length at Max Absorbancy (A)	Transmittancy at 10,000 A (%)
Fluorescein	4,750	100
Methyl orange	4,250	100
Ferric chloride	4,400	98
Permanganate	5,250	98
Methyl red	5,300	100
Bromocresol green	6,170	100
Methylene blue	6,250	100
Copper-ammonia complex	6,500	98

With the initial difficulties of particle size and color minimized, the problem resolved itself into an application of the laws of colorimetry. Briefly, the laws of interest in this study are:

1. Lambert's—At constant concentration the amount of light which is absorbed in passing through a minute layer of a homogeneous liquid is directly proportional to the intensity of light.

2. Beer's—Absorption of light in a layer of liquid is proportional to the number of absorbing particles or weight concentration.

3. Ostwald's—The absorption maximum of a colloidal solution shifts with

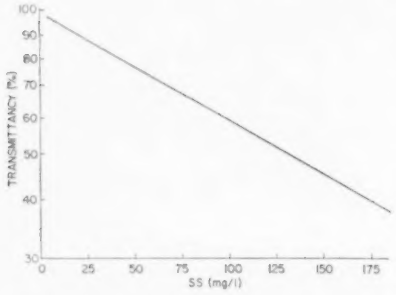

FIGURE 3.—Relationship between suspended solids and transmittancy. Results from approximately 3,000 suspended solids determinations (Gooch method) were used to plot this curve.

increasing dispersion toward the shorter wave lengths (4).

Manipulation in the higher wave lengths was desirable to eliminate color interference and to lessen involvements with Ostwald's law.

Evaluation Procedure

Inasmuch as no "standard" sewage sample was available for test purposes, compliance with the light laws had to be evaluated by another method. Over a period of two years, samples of raw sewage, clarifier influent, clarifier effluent, and non-settleable clarifier influent were examined for their suspended solids content by both the Gooch and spectrophotometric procedures (see Appendix). The results were plotted as the logarithm of transmittancy against suspended solids concentration (Figure 3). The analytical results from the Gooch method were used as the true value of the suspended solids and the concentrations encountered varied from 20 to 480 mg/l. As the plotted points began to form a straight line, the hoped-for compliance with the pertinent light laws seemed to be realized.

The limits of the instrument were arbitrarily set at from 30 to 90 per cent transmittancy. Samples with readings below 30 per cent were diluted so that transmission would fall somewhere between the selected values. In initial experiments the sewage was diluted with distilled water; however, it was discovered that when sewages containing more than 180 mg/l of suspended solids were diluted this way, the results consistently fell below the Gooch results. Additional experiments showed distilled water to be capable of dissolving some of the suspended matter in sewage. Now filtered sewage or sewage from which the settleable solids have been removed is used as dilution water and the results have been gratifying. Tap water as a diluent also gave reproducible results which were in agreement with the Gooch results.

A further test to determine if the light laws were being respected was made by diluting a suspension of sewage with a known concentration of suspended solids. Dilutions were made using city water at the same temperature as the sewage (Table IV). The diluted sewage samples were essentially identical with the calculated points thus demonstrating that the suspended solids concentration is directly proportional to the amount of light transmitted.

Precision

Next the precision of the Gooch and photometric methods was tested. Tables V, VI, and VII show some of the data in three different concentra-

TABLE IV.—Comparison of Gooch and Spectrophotometric Methods on a Standard Sewage Sample *

Dilution		Gooch SS† (mg/l)	Spectro. SS (mg/l)	Calc. SS (mg/l)
Parts of Sewage	Parts of Tap Water			
3	1	173	176	176
2	2	111	119	118
1	3	62	59	59

* Sample contained 235 mg/l of SS (avg of 10 Gooch determinations).

† Avg of 5 Gooch determinations.

tion ranges. On 10 different occasions samples were blended and 10 replicate samples were run using the Gooch and photometric methods. The mean values of the suspended solids content for the 10 series of Gooch determinations ranged from 59 to 256 mg/l; for the photometric method the mean values ranged from 58 to 247. The standard deviations for the Gooch method ranged from 3 to 8 mg/l and for the photometric method they ranged from 1 to 5.

It may seem odd that better precision is obtained using the photometric method since originally the photometric method was evaluated from the Gooch results. This oddity can be explained by the fact that the straight line in Figure 3 was fitted after plotting the results from approximately 3,000 Gooch determinations. Inasmuch as an extremely large number of analytical results was employed in plotting the curve and the original Gooch results so often fell on the curve (as shown in Table VIII), the method for determining precision was judged to be statistically reliable.

TABLE V.—Suspended Solids in Grab Sample of June 21, 1957

Gooch SS (mg/l)	Spectro. SS (mg/l)
206	203
210	203
207	203
203	208
203	208
190	204
213	203
200	204
196	204
198	208

TABLE VI.—Suspended Solids in Grab Sample of July 26, 1957

Gooch SS (mg/l)	Spectro. SS (mg/l)
100	125
120	123
121	125
122	123
121	125
116	120
128	123
130	123
132	125
122	123

TABLE VII.—Suspended Solids in Grab Sample of July 20, 1957

Gooch SS (mg/l)	Spectro. SS (mg/l)
60	54
58	57
66	61
62	55
52	57
58	57
56	55
58	62
61	60
60	60

TABLE VIII.—Six Month's Selected Data for Plotting Curve in Figure 3

Gooch SS (mg/l)	No. of Occurrences	Times these Values Fell on the Fitted Curve
190	4	4
180	7	7
170	4	4
160	13	12
150	17	16
140	12	12
130	18	18
120	26	25
110	28	28
100	34	33
90	27	26
80	38	37
70	18	18

Summary and Conclusions

A program was undertaken to establish a time-saving method for the determination of suspended solids in sewage. The proposed spectrophotometric method is more rapid than the Gooch procedure outlined in "Standard Methods" (1). The data reveal conformance with the pertinent laws of colorimetry.

Acknowledgment

The authors wish to express appreciation for the cooperation and assistance of the entire laboratory staff during the course of this investigation and to Mr. George F. Fynn, Plant Superintendent, for his aid and direction.

APPENDIX

Gooch Crucible Method

Apparatus

Gooch crucibles
Vacuum arrangement
Drying oven
Desiccator

Procedure

Prepare a mat of acid-washed asbestos fibers (2 mm thick) in a Gooch crucible or a porous bottom porcelain crucible. Dry the crucible in an oven at 103°C for one hour, cool, and weigh. Place the Gooch crucible on a suction flask and measure out 100 ml of well-mixed sewage, keeping the solids in suspension while measuring. Filter the sample through the prepared crucible and follow with several distilled-water rinsings of the graduate. Be sure that all the suspended matter is transferred to the crucible. Dry in an oven at 103°C for one hour, cool, and weigh to constant weight.

Spectrophotometric Method

Apparatus

Spectrophotometer
Blender
Siphon system
Battery jar
Stirrer (electric)

Procedure

Shake sample well and pour about 700 ml into the cylinder of the blender. Blend for 1½ min (use stop watch) and transfer blended liquor to a battery jar and stir. While stirring, siphon about 25 ml into the cuvette. With a 10,000-A setting, read the transmittancy or absorbance scale using water as a blank. Just before reading, invert the cuvette gently to make sure all the particles are in suspension. Do not shake the cuvette as air bubbles interfere with the reading. Read concentration of suspended solids from prepared graph.

References

1. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
2. Holmes, G. W., "Determination of Suspended Solids in Sewage by Light Absorption." *Sewage Works Jour.*, **7**, 4, 642 (July 1935).
3. Willard, H. H., Merritt, L. L., and Dear, J. A., "Instrumental Methods of Analysis." D. Van Nostrand Co., Inc., New York, N. Y. (1949).
4. Snell, F. D., and Snell, C. T., "Colorimetric Methods of Analysis." 2nd Ed., D. Van Nostrand Co., Inc., New York, N. Y. (1936).

TEN-YEAR INDEX READY

The Ten-Year Index to SEWAGE AND INDUSTRIAL WASTES, covering the period of 1949–58, can now be obtained from the Federation office. See page 460a for complete details.

Industrial Wastes

THERMAL CONSIDERATIONS IN THE STORAGE OF RADIOACTIVE WASTES IN SALT FORMATIONS*

By Robert S. Schechter and Earnest F. Gloyna

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The ultimate disposal of high-level radioactive wastes has become one of the most important problems of this age. Reactor fuel wastes and perhaps radioactive wastes from other sources are characterized by a high concentration of radioactive isotopes which must be contained for at least several generations. Ultimate containment therefore must be permanent, provide the necessary shielding, and cope with the generated heat resulting from radioactive isotope decay. Such ultimate containment appears to be feasible in massive salt formations, for many salt domes and beds are geologically stable, structurally sound, homogeneous in nature, inert to many wastes, accessible, and relatively inexpensive to construct.

The thermal stresses which develop around a salt cavity are important factors in cavity design and have not been analyzed previously. However, these stresses can be computed after detailed information is available relative to anticipated temperatures. This paper describes a generalized scheme for developing these temperature data.

Previous Work

The problem of designing safe and permanent underground storage facilities for radioactive wastes is complicated by the generation of heat within the waste. One of the important parameters in design is the temperature rise within the underground cavity and in the vicinity of the cavity. Theoretical estimations of this temperature rise have been made by Birch (1), Parker *et al.* (2), and Schechter and Gloyna (3).

Two models of thermal transport have been proposed and considered by these investigators. The view which appears to represent the best approximation is one of a spherical cavity filled with liquid waste of a uniform temperature and heat being dissipated into an infinite mass of salt by conduction. The assumption regarding the uniformity of cavity temperature is probably valid because of the natural convective mixing and the relatively long period (2 to 3 yr) required for the contents of the cavity to become warmed to the maximum temperature. This model has been explored analytically by Birch (1) for an exponential relationship between time and the volumetric rate of heat generation. In addition, Birch has also computed a few selected values of the temperature increase (Birch's analytical result was in integral form and numerical computations are required). Schechter and Gloyna (3) independently considered the same model, and previously performed extensive computations based on a volumetric rate of heat generation expressed as a fourth order poly-

* Presented at the Fifth Nuclear Engineering and Science Conference; Cleveland, Ohio; Apr. 5–10, 1959.

TABLE I.—Heat Generation Constants for Radioactive Waste of Uniform Temperature Confined within a Spherical Cavity of a Salt Formation*

Age of Material (yr)	Specific Power (megawatts/ton)	Irradiation† (megawatt days/ton)	Range of Validity (hr)	A_0	A_1	A_2	A_3	A_4
2	33	10,000	0–75,000	50.04	-0.2779×10^{-2}	$+0.1046\times10^{-6}$	-0.1806×10^{-11}	$+0.1100\times10^{-16}$
6	33	10,000	0–50,000	17.87	-0.1927×10^{-2}	-0.1294×10^{-8}	$+0.1032\times10^{-12}$	-0.1071×10^{-17}
10	33	10,000	0–50,000	12.54	-0.1029×10^{-2}	$+0.1334\times10^{-7}$	-0.1860×10^{-12}	$+0.1242\times10^{-18}$
2	33⅓	3,300	0–75,000	17.20	-0.8991×10^{-3}	$+0.2769\times10^{-7}$	-0.4086×10^{-12}	$+0.2233\times10^{-17}$
6	33⅓	3,300	0–50,000	5.59	-0.1159×10^{-2}	$+0.2923\times10^{-6}$	-0.5620×10^{-10}	$+0.4612\times10^{-14}$
2	33⅓	330	0–75,000	1.851	-0.9964×10^{-4}	$+0.3105\times10^{-8}$	-0.4570×10^{-13}	$+0.2484\times10^{-18}$
6	33⅓	330	0–50,000	0.5808	-0.8784×10^{-5}	$+0.5237\times10^{-10}$	$+0.2345\times10^{-14}$	-0.3569×10^{-19}

* For the equation $Q = A_0 + A_1 t + A_2 t^2 + A_3 t^3 + A_4 t^4$, where Q = heat generation in Btu/hr/cu ft, and t = time in hours measured from age of material (see first column in table).

† All values are based on a reactor with a thermal neutron flux of 10^{14} n/sec/sq cm using a natural uranium fuel, and assuming that 800 gal of waste are produced per ton of uranium processed.

nomial. The basic idea for the polynomial was obtained from Blomeke and Todd (4). These coefficients are given in Table I. Using this model, curves were constructed to relate the maximum temperature increase to the properties of the waste such as age of the waste, power level of the reactor, total irradiation time, and dilution; and to the physical and geometric properties of the system.

Another "picture" of the thermal transport mechanism is obtained by neglecting mixing within the cavity and assuming that the heat is transported by conduction from within the cavity as well as in the salt mass. Parker, Hemphill, and Crowell (2) have used this model in studying the thermal effects based on both a constant volumetric heat generation term and an exponential decay model. Birch (1), and Schechter and Gloyna (3) have also considered this model for a number of situations.

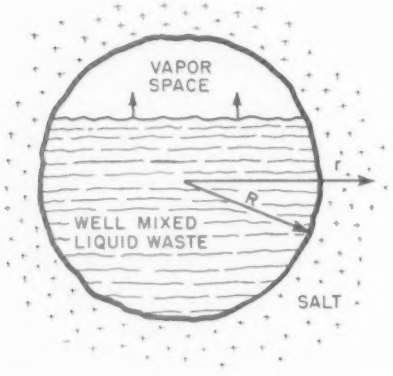

FIGURE 1.—The model showing waste within a cavity in a salt formation.

The results reported herein encompass the effect of vapor space in a partially filled cavity and the temperature distributions in space as well as in time, using this refined model.

Mathematical Model*

The heat generated by the radioactive decay in materials stored within underground cavities is accountable in three ways. A portion of the heat is dissipated into the surroundings by conduction; the remaining portion of the heat must be stored within the cavity in the form of either sensible or latent heat.

In a small interval $\Delta\theta$, the amount of heat generated (in Btu) within a sphere of radius R (Figure 1) is

$$\psi \tfrac{4}{3}\pi R^3 Q(\theta)\Delta\theta \ldots\ldots\ldots\ldots (1)$$

and the heat flow (in Btu) to the surroundings is given by

$$-4\pi R^2 k_r \frac{\partial T(R,\theta)}{\partial r}\Delta\theta \ldots\ldots (2)$$

The increase in sensible heat of the waste is evidenced by an incremental

* See Appendix for nomenclature.

change in the temperature of the waste within the cavity. Assuming the contents of the cavity to be uniform, the sensible heat increase is

$$\tfrac{4}{3}\pi R^3[\psi C_{p_L}\rho_L + (1-\psi)C_{p_g}\rho_g]\Delta T(R,\theta) \quad (3)$$

If it is assumed that the changes in temperature occur slowly (this assumption is borne out by the numerical results), then the stored waste must exert its vapor pressure at all times. Consequently, a temperature change will produce a corresponding change in the vapor pressure of the liquid waste; and the amount of heat which is stored as latent heat is

$$\frac{\tau(1-\psi)\tfrac{4}{3}\pi R^3\Delta p}{\bar{R}[T(R,\theta)+460]} \quad (4)$$

Often the relationship between temperature and vapor pressure can be expressed in the form

$$p = A\ 10^{B/T(R,\theta)+C} \quad (5)$$

By substituting Equation 5 for the pressure term in Equation 4, it is possible to obtain the relationship for latent heat

$$\frac{-B\tfrac{4}{3}\pi R^3(1-\psi)A\tau[10^{B/T(R,\theta)+C}\ln 10]\Delta T(R,\theta)}{\bar{R}[T(R,\theta)+460][T(R,\theta)+C]^2} \quad (6)$$

For simplicity, the increase in latent heat can be rewritten as

$$\phi[T(R,\theta)]\Delta T(R,\theta)$$

Equating the heat generation term to the storage and dissipation terms and allowing $\Delta\theta$ to approach zero, then

$$\tfrac{4}{3}\pi R^3 Q(\theta) = -4\pi R^2 k_s \frac{\partial T(R,\theta)}{\partial r} + \tfrac{4}{3}\pi R^3\left\{\psi C_{p_L}\rho_L + (1-\psi)C_{p_g}\rho_g + \phi[T(R,\theta)]\right\}\frac{\partial T(R,\theta)}{\partial\theta} \quad (7)$$

The flow of heat into the surroundings is by conduction and the temperature as a function of time and position is given by the relationship

$$\alpha\left[\frac{\partial^2 T(r,\theta)}{\partial r^2} + \frac{2}{r}\frac{\partial T(r,\theta)}{\partial r}\right] = \frac{\partial T(r,\theta)}{\partial\theta} \quad (8)$$

Equation 7 expresses the boundary condition at $r = R$. The remaining two boundary conditions are

$$T(r,\theta) = T_e \quad \text{at} \quad r = \infty \quad (9a)$$

and

$$T(r,\theta) = T_e \quad \text{at} \quad \theta = 0 \quad (9b)$$

To simplify the numerical computation, certain variables are defined as

$$\rho = \frac{r}{R} \quad (10a)$$

$$t = \frac{\alpha}{R^2}\theta \quad (10b)$$

$$V = T(r,\theta) - T_e \quad (10c)$$

Equations 7, 8, and 9 can now be written as

$$\psi\frac{R^2}{\alpha}Q\left(\frac{R^2}{\alpha}t\right) = -\frac{3k_s}{\alpha}\frac{\partial V(1,t)}{\partial\rho} + \{\psi C_{p_L}\rho_L + (1-\psi)C_{p_g}\rho_g + \phi[V(1,t) + T_e]\}\frac{\partial V(1,t)}{\partial t} \quad (11)$$

$$\frac{\partial^2 V(\rho,t)}{\partial\rho^2} + \frac{2}{\rho}\frac{\partial V(\rho,t)}{\partial\rho} = \frac{\partial V}{\partial t} \quad (12)$$

$$V(\rho,t) = 0 \quad \text{at} \quad \rho = \infty \quad (13a)$$

$$V(\rho,t) = 0 \quad \text{at} \quad t = 0 \quad (13b)$$

The solution of this system of equations can be developed by LaPlace

transform and is

$$V(\rho,t) = \frac{1}{\rho}\int_0^t \frac{\partial V(1,\epsilon)}{\partial \epsilon}\left[erfc\frac{\rho-1}{\sqrt{t-\epsilon}}d\epsilon\right] \quad (14)$$

Further analytical development is hampered by the nonlinear nature of the temperature relationship at the cavity surface and a numerical attack is necessary.

Numerical Method

Many possible methods of analysis were examined. However, in order to minimize computation time, a technique of analysis which has been proposed by Wissler and Schechter (5) was adopted. This procedure is outlined as follows.

Equation 14 can be differentiated with respect to ρ and the temperature gradient evaluated at $\rho = 1$. By substituting the resulting expression into Equation 11, it is possible to develop Equation 15.

$$\psi\frac{R^2}{\alpha}Q\left(\frac{R^2}{\alpha}t\right) - U[V(1,t)+T_c]\frac{\partial V(1,t)}{\partial t} = \frac{3k_s}{\alpha\sqrt{\pi}}\int_0^t \frac{\partial V(1,\epsilon)}{\partial \epsilon}\frac{d\epsilon}{\sqrt{t-\epsilon}} \quad (15)$$

The temperature within the cavity between time $(n-2)\Delta t$ and $n\Delta t$, where Δt is some small time increment is then approximated by the polynomial

$$V(1,t) = a_0 + a_1[t-(n-2)\Delta t] + a_2[t-(n-1)\Delta t]\times[t-(n-2)\Delta t] \quad (16)$$

This polynomial can be substituted into Equation 15, and the resultant expression rearranged in the following form:

$$a_2 = \frac{\psi\frac{R^2}{\alpha}Q\left(\frac{R^2}{\alpha}n\Delta t\right) - I - \frac{3k_s}{\sqrt{\pi\alpha}}a_0 - a_1\left\{6\frac{k_s\Delta t}{\sqrt{\pi\alpha}} + U + \frac{2^{\frac{1}{2}}3\Delta t^{\frac{1}{2}}k_s}{\sqrt{\pi\alpha}}\right\}}{3\Delta t U + \frac{3k_s}{\sqrt{\pi\alpha}}2^{\frac{1}{2}}\left(\frac{5}{3}\right)\Delta t^{\frac{3}{2}} + \frac{6k_s}{\sqrt{\pi\alpha}}(\Delta t)^2} \quad (17)$$

where

$$U = \psi C_{p_L}\rho_L + (1-\psi)C_{p_g}\rho_g + \phi(V[1,(n-1)\Delta t] + T_c)$$

and

$$I = \int_0^{(n-2)\Delta t}\frac{\partial V(1,\epsilon)}{\partial \epsilon}\frac{d\epsilon}{\sqrt{n\Delta t-\epsilon}}$$

If the temperatures $V(1,0)$ and $V(1,\Delta t)$ are known, then a_2 can be computed from Equation 17. Now the new temperature $V(1,2\Delta t)$ can be determined from Equation 16. Thus $V(1,\Delta t)$ and $V(1,2\Delta t)$ are obtainable and by an identical procedure it is possible to determine $V(1,3\Delta t)$. The whole process can then be repeated until the entire time distribution of cavity temperatures is known at the discrete time steps Δt.

The temperature $V(1,\Delta t)$ which is necessary to begin the process can be obtained from a Taylor series expansion of the temperature around the point $t = 0$. The integral I was evaluated by Simpson's rule.

Once the distribution of liquid temperatures has been established, the spatial variation of temperature can be computed by numerically integrating Equation 14.

The results displayed in this paper were obtained using an IBM 650 computer.

Discussion of Results

Before discussing the results obtained for the particular set of physical properties used in the numerical computation, it is instructive to note the possible error. For example, the effect of temperature on the thermal con-

ductivity of salt has been neglected in making the calculations. However, the thermal conductivity of rock salt decreases rather markedly with temperature (1).

To ascertain the effect of the thermal conductivity on the temperature rise, a calculation was made in which only the thermal conductivity was varied. These results are shown in Figure 2. The difference between the two curves is significant—being of the order of 100°F at the point of maximum temperature. This large difference in temperature due to variations in the thermal conductivity indicates two pertinent conclusions.

1. The numbers reported here should be considered as functions of the particular set of physical parameters, which were selected as being representative (Table II).

2. A large number of computations should be made for a range of physical constants and for other theoretical models in order to establish the limits of temperature variation. The use of field experiments appears limited by the long time required (2 to 4 years) to attain the peak temperatures. Experi-

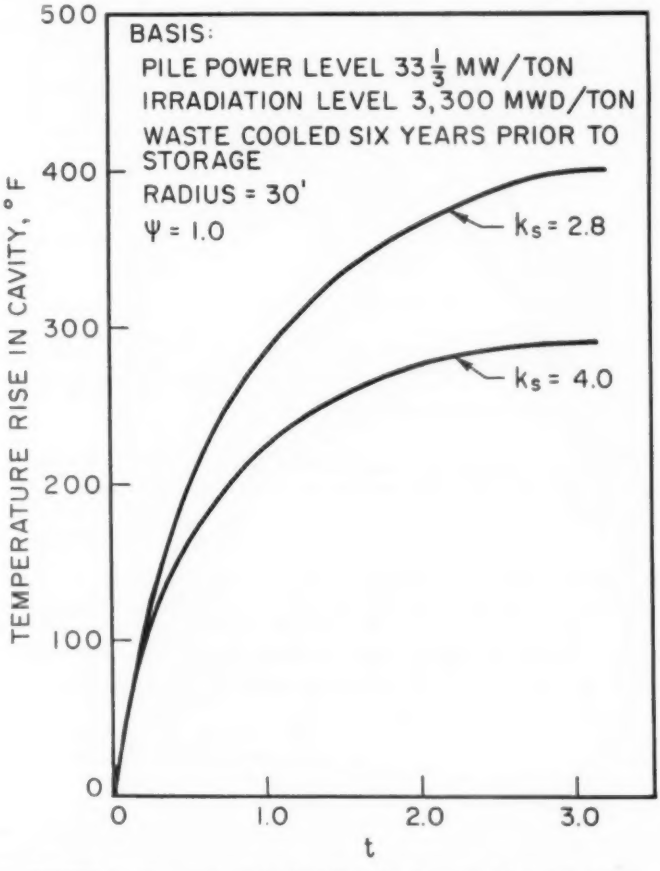

FIGURE 2.—Temperature rise in full cavity shown as a function of time for two different thermal conductivities of salt.

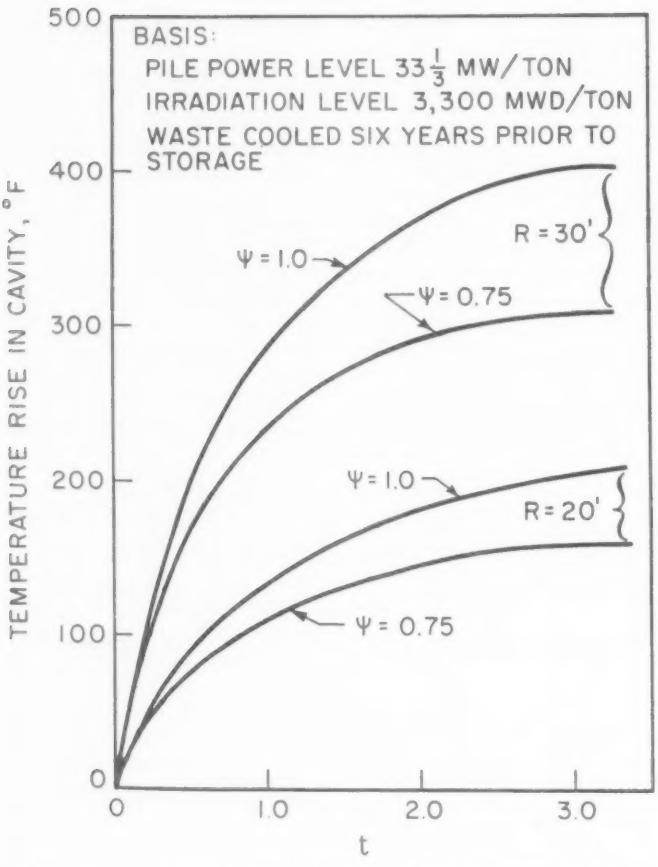

FIGURE 3.—Variation of temperature excess with time within the cavity as a function of cavity radius and fraction of total volume occupied by the liquid waste.

TABLE II.—Values of Physical Parameters

Parameter	Value
ρ_L	62.4 lb/cu ft
C_{P_L}	1.0 Btu/lb/°F
ρ_g	0
C_{P_g}	0

Constants*	Value
A	1
B	−3002.778°F
C	378.4°F
T_s	100°F
k_s	2.8 Btu/hr/ft/°F
α	0.1012 sq ft/hr

* In vapor pressure equation.

ments using models in conjunction with a reasonable scale-up procedure might yield some useful information.

It is important to note that the heat capacity and the density of the waste have also been assumed to be constant with respect to temperature. These two parameters are also temperature sensitive, especially in the region above 500°F.

Figures 3 and 4 display the variation of temperature excess within the cavity both as a function of cavity radius and a fraction of total volume occupied

by the liquid waste. The decrease in temperature noted in the partially filled cavity was not proportional to the decrease in volume of the radioactive waste; that is, a 25-per cent decrease in the amount of waste injected into a particular cavity did not result in a 25-per cent decrease in the temperature. This inequity is due to the relatively small value of the density of the gas (taken as being negligible in all computations) as compared to the liquid. This difference in density is not offset by the heat necessary to vaporize the amount of liquid needed to satisfy the equilibrium requirement which is stipulated in the model.

For example, the vapor pressure of water increases from 10 to 14.7 psia when the temperature is increased from 193 to 212°F. On the basis of a cubic foot of vapor space, approximately 6.6×10^{-3} lb-moles of liquid must be vaporized to increase the pressure by 4.7 psi. Presuming the latent heat to be approximately 1.8×10^4 Btu/lb-mole, it can be seen that

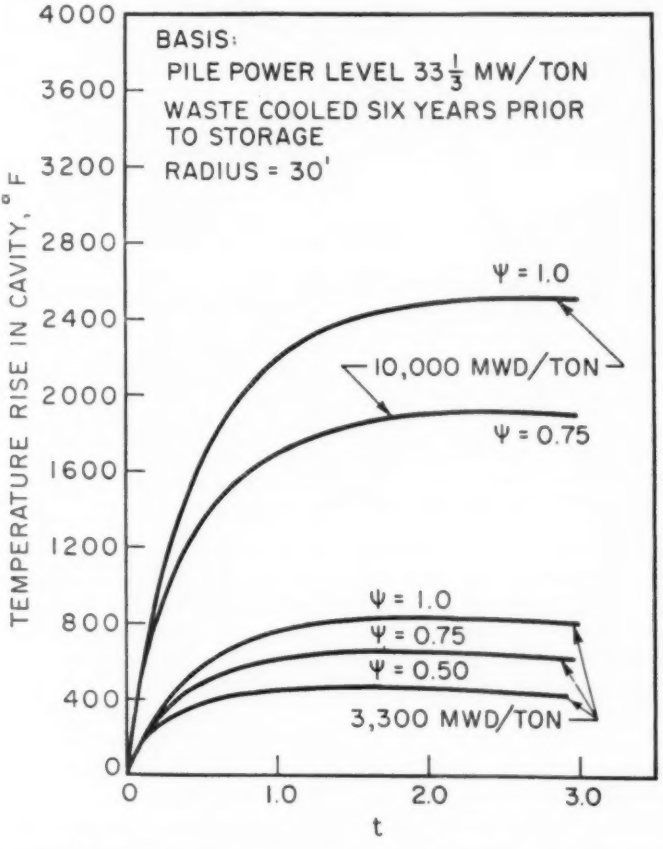

FIGURE 4. Variation of temperature excess with time within the cavity as a function of the fraction of total volume occupied by the liquid waste and at different irradiation levels.

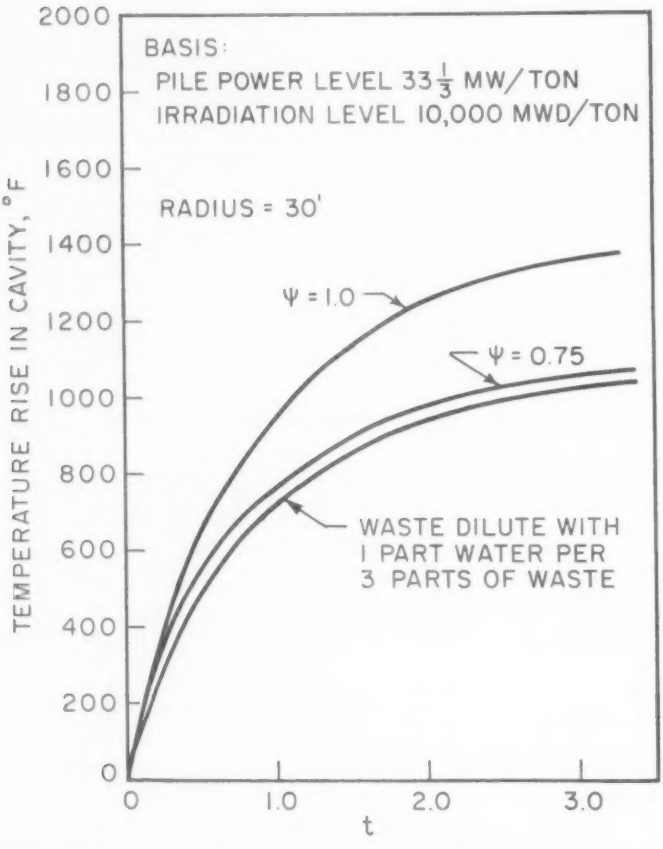

FIGURE 5.—Variation of temperature excess with time for cavities containing dilute waste, 25-per cent vapor space, and no excess vapor space. Waste cooled two years prior to storage.

the amount of heat absorbed as latent heat is approximately 120 Btu. On the other hand, presume that this cubic foot is occupied by water. Then approximately 1,140 Btu are required to heat the cubic foot of water from 193 to 212°F.

From this, it can be concluded that the vapor space should be just sufficient to accommodate the volume increase of the liquid due to thermal expansion and that it is far more effective to dilute the waste with a material of high density and heat capacity to reduce temperature increase to permissible levels than it is to partially fill the cavity. This conclusion is shown in Figure 5, where the temperature increase for two spherical cavities containing identical quantities of waste is plotted as a function of time. One cavity contains the diluted waste and the other has a 25-per cent vapor space.

The temperature distribution as a function of distance and time is shown for a particular example in Figure 6. The spatial distribution of temperatures is important in the structural considerations especially for cavities which are located at moderate depths.

Conclusions

1. The methods developed herein are valuable in deriving the temperature distribution both as a function of time and position for a general model.

2. It appears that cavities much in excess of 30 ft in radius will produce temperature increases in the waste which in all probability are beyond permissible limits.

3. The waste should be diluted to reduce the temperature rise rather than partially filling the cavity with the undiluted waste.

4. The temperatures are sensitive to changes in the values of the physical parameters.

Acknowledgment

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References

1. Birch, F., "Thermal Considerations in Deep Disposal of Radioactive Wastes." Natl. Acad. Sci., Natl. Res. Counc. Pub. 588 (1958).
2. Parker, F. L., Hemphill, L., and Crowell, J., "Status Report on Waste Disposal in Natural Salt Formations." ORNL 2560 (Sept. 1958).
3. Schechter, R. S., and Gloyna, E. F., "Temperature Rise in Underground Storage Sites for Radioactive Wastes." A.I.Ch.E., Symposium Series Vol. on Nuclear Sci. and Eng., in press (submitted Mar. 1, 1958).
4. Blomeke, J. O., and Todd, M. F., "Uranium-235 Fission-Product Production as a Function of Thermal Neutron Flux, Irradiation Time, and Decay Time." ORNL 2127, 2, Part 1 (Aug. 1957).
5. Wissler, E. H., and Schechter, R. S., unpublished notes.

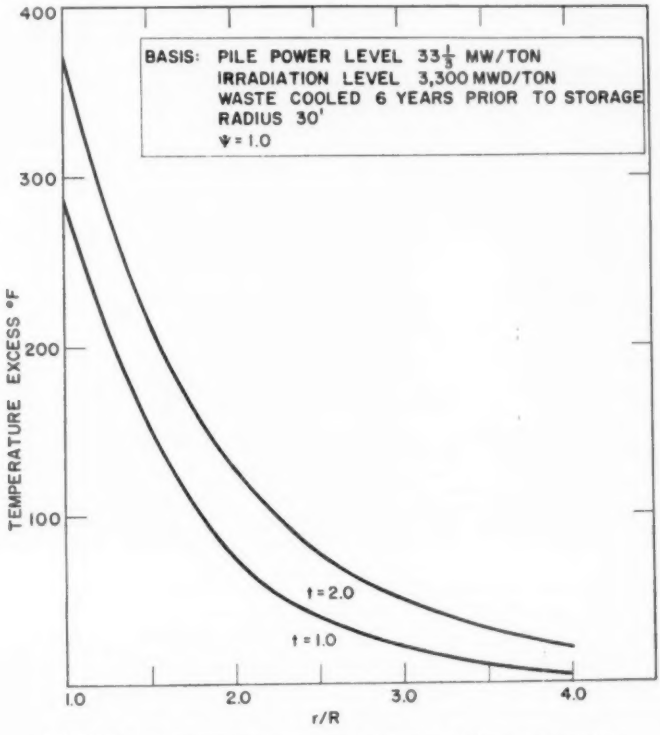

FIGURE 6. Temperature excess as a function of time and position.

APPENDIX—NOMENCLATURE

A, B, C = Constants;
C_{p_L} = Heat capacity of liquid waste, Btu/lb/°F;
C_{p_g} = Heat capacity of gas, Btu/lb/°F;
k_s = Thermal conductivity of salt, Btu/hr/ft/°F;
P = Vapor pressure of liquid, atm;
$Q(\theta)$ = Volumetric rate of heat generation, Btu/hr/cu ft;
R = Radius of spherical cavity, ft;
r = Position radius, ft;
$\bar{R}$ = Gas constant, consistent units;
T = Temperature, °F;
t = Dimensionless factor, $\frac{\alpha}{R^2}\theta$;
V = Temperature excess, °F;
α = Thermal diffusivity of salt, sq ft/hr;
θ = Time, hr;
ρ_L = Density of liquid, lb/cu ft;
ρ_g = Density of gas, lb/cu ft;
ρ = Dimensionless factor, $\frac{r}{R}$;
τ = Latent heat, Btu/lb-mole; and
ψ = Fraction of total volume filled with waste.

"MR. WATER WORKS" HONORED

Harry E. Jordan, who retired September 1 after 23 years as Secretary of the American Water Works Association, is shown at the left receiving a permanent "Mr. Water Works" emblem from Lewis S. Finch, Vice-President of the Indianapolis Water Company and retiring AWWA President, at the "Salute to Harry E. Jordan" dinner which highlighted the annual meeting in San Francisco in July.

COMPOSTING WASTE SLUDGE FROM PHARMACEUTICAL MANUFACTURING*

By A. J. Gabaccia

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Evaluation of the literature on composting methods reveals that there has been much valuable information published on composting of garbage and animal wastes. However, there is not much data available on composting of sludges from combined domestic and industrial waste treatment plants.

At the Pearl River plant of Lederle Laboratories from 6 to 10 tons per day of organic sludges are accumulated for disposal. This comes from fermentation of antibiotics, extraction of pharmaceuticals from animal livers, stabling of animals, and the sanitary sewage from 4,000 employees. Composting was included with other disposal methods in a study program for determination of a practical solution to this problem.

Scope of Study

The immediate scope of this investigation consisted of answering two questions:

1. Can this industrial sludge be composted?
2. If so, can a routine composting procedure be established?

The investigational program was carried on within the following outline:

1. A literature study on existing composting methods and practices to determine how they could be applied to this problem.
2. Pilot-plant investigation and outdoor field experiments on some established composting methods.
3. Discussions with outside interested parties and with people actively engaged in composting.

From the preliminary study the following observations were made:

1. Most of the established investigations and reported data pertained to composting of garbage and farm wastes. Composting of industrial sludges has not been studied very intensively. It was believed that modifications on existing composting procedure would be needed to cope with the problem.
2. Successful composting requires a knowledge and use of the principles controlling material handling and corrosion. This is especially true in rapid composting where machinery is used in handling the materials being composted.
3. It was noted that the outstanding difference between the Lederle industrial sludge and the garbage type of waste was that the composition of pharmaceutical sludge remained fairly constant on an annual basis whereas garbage wastes have seasonal variations. The carbon to nitrogen ratio of Lederle sludge remained about 15:1 while garbage waste is reported to range from 10:1 to 80:1. Also, the operational control of the treatment plant provided the advantage that the industrial sludge containing domestic and animal solids would be free of such foreign matter as cardboard, tin cans, polyethylene wrappings, and glass. For the majority of the garbage com-

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

posting methods, the first problem is the removal of these items prior to composting.

4. A disadvantage for investigators of composting procedures is the lack of a common yardstick to follow the progress of composting and to establish an end point of decomposition.

Pilot Plant

It is known that under correct conditions decomposition of organics is brought about by the action of microorganisms, both aerobic and anaerobic in many stages. These experiments were planned so as to determine the required conditions and to define the purpose of each digestion stage.

The pilot-plant investigations began at Pearl River in the summer of 1953 using a "Multi-Stage Composting" * procedure. In this procedure one day is specified as the time to complete one full stage or cycle of decomposition. The total number of stages would be determined by experiment.

The objectives were to establish, isolate, study, and report the characteristics of the many digestion steps or stages in composting of these sludges. The equipment used for this method consisted of wooden boxes with a capacity of about one yard, equipped with movable top and bottom doors, a small forklift tractor, a small front-end loader, and a shredding machine. Metal bars were attached to the sides of each box so that when the box was placed on a stationary jib, the contents could be discharged quickly and processed by hand shovel or by tractor.

The objective of this procedure was to provide for the development of an optimum bacterial population in the various stages.

Variable Conditions Encountered

It soon became obvious that the known variables in composting would be encountered in this work. It was found that the first important variable to control, especially in the early stages, was the moisture content. This decision was based, not on composting criteria, but on the practicalities of material handling. By trial and error, a suitable moisture content of the initial material for satisfactory physical handling was established. The sludge was diluted with barn manures containing straw bedding and wood sawdust. The ideal blend which gave the good composting results and was suitable for physical handling was:

Material	Per Cent by Weight
Treatment plant sludge	65
Stable manures	25
Sawdust	10

In addition, ½ lb of finely divided phosphate rock was added for each 100 lb of mixture. This blend, with a resultant moisture content of between 50 and 60 per cent, became the influent material for the first stage of composting.

Before being added to the compost, the treatment plant sludge is dewatered on vacuum filters, using chemical coagulants to aid in the dewatering process. At one time these were ferric chloride and lime, but the iron in the finished compost was found to be harmful to lawns on which the compost was applied. For this reason the use of iron coagulant was discontinued and the dewatering was accomplished with lime. The resultant sludge cake varies from 65- to 85-per cent water and is of the approximate composition shown in Table I. This table also shows the composition of the remaining raw materials for the compost.

The second variable believed critical for material in the early stages is pH. The treatment plant sludge with chemical additives has a pH of about 7.5 to 8. The pH of animal wastes also is alkaline. The sawdust has an initial pH of 3.0 to 4.0. But the mixed ingredients, after about one day,

* Patented process resulting from developments in this work.

have a pH of 6.5 to 7.5, which is satisfactory for composting of the wastes.

The box system permitted testing by trial and error some of the other important variables in composting, such as temperature, aeration, blending, reseeding, compactness, and reduction of particle size.

An important factor in composting is to achieve proper temperature in the process. Fortunately composting masses have good insulation properties and retain the heat from the reactions, thereby maintaining elevated temperatures. High temperatures are required for the destruction of undesirable weeds and of pathogenic organisms. A temperature pattern is shown in Table II.

An important tool in studying these variables was a shredding machine.* This machine conveys the material by fast moving belt through a small opening under spring tension metal bars and throws it out three or four feet into the air. Some of the advantages accomplished by shredding were aeration, evaporation of water, reduction in particle size, and blending of material.

Routine Procedure

By using a gas analysis instrument, the compost material was probed to determine CO_2 and O_2 contents. It was noted that frequent shredding of material with an age of over two days definitely shortened the total composting time. From the results of many trials a routine procedure was established so as to produce satisfactory decomposition of these wastes in six to eight days. The pertinent points in this procedure are:

1. The sludge was diluted with animal manures and sawdust to give a moisture content between 50 and 60 per cent. This represented a mixture of about 65 per cent sludge and 10 per cent sawdust. Phosphate rock was added representing about 0.5 per cent of the batch weight.

2. This mixture was seeded with about 10 per cent of material with an age of one stage or in this case one day.

3. After thorough mixing the total blend was shredded and stored for 24 hr.

4. The material in the other stages also was shredded daily, reseeding with 10 per cent of material one stage older.

TABLE I.—Approximate Composition of Wastes from Lederle Laboratories Pearl River Plant

Item	Stable Manure (per cent)	Waste Treatment Plant Sludge (per cent)	Compost (per cent)
Moisture content	70	65–85	35
Organic content	—	70	80
Nitrogen	1.5	2–3	2.0
Phosphorus	0.1	0.1–0.3	0.8
Potassium	0.3	0.7	0.8

TABLE II.—Compost Moisture Content, Chemical Oxygen Demand and Temperature Record

Age (days)	Moisture Content (per cent)	COD (mg/25 g dry sample)	Temperature (°F)
1	65	12.0	100
2	60	9.0	120
3	55	8.5	140
4	50	8.0	160
5	40	7.5	160
6	35	7.0	130
7	<35	6.5	110

Evaluation of Process

One of the common problems in composting studies is the establishment of an end point to determine when composting is satisfactorily complete. Some known end points are recorded as moisture content, lack of odor and flies, and experienced visual observations. The objective in composting is to stabilize putrescible matter and to make it unattractive to flies and rodents and as odor free as possible.

* Royer Shredder.

For these tests a more specific end point would be advisable. Accordingly, it was decided to modify slightly the COD test for evaluation of the compost as given in "Standard Methods" (1). In brief, the modified test consisted of adding 0.25 g of dry sample to 50 ml of 1 N potassium dichromate, 50 ml of distilled water, and 100 ml of sulfuric acid. After one hour of refluxing and cooling to room temperature the solution was diluted to one liter volume with distilled water. A 250-ml aliquot of this solution was titrated with 0.5 N ferrous ammonium sulfate using O-phenanthroline as an indicator. For convenience in reporting, the COD values shown in Table II are converted to mg/25 g dry compost.

Michigan State Tests

The Pearl River composting problem was studied, using the modified Earp-Thomas metal digester which was being tested at Michigan State University (2) with garbage. A full-scale experiment on Lederle waste was outlined using these composting facilities consisting of bucket conveyor, an eight-deck, 8- × 22-ft insulated digester, and storage area. Approximately 30 tons (130 drums) of pharmaceutical wastes were prepared and trucked from Pearl River to the composting site in East Lansing. The blend of waste consisted of 60 per cent sludge, 30 per cent coffee grounds, and 10 per cent animal manures. The moisture content was below 60 per cent.

The objectives of this proposed experiment were to determine: (a) whether the waste be composted by this method and machinery, (b) the rate of decomposition in the digester, (c) the performance and efficiency of the digester, and (d) feasibility of consideration for full-scale composting of the waste.

The description of this digester, as reported by Snell (3) is an 8- × 22-ft cylindrical metal tank divided into 8 sections or stages, each supplied with metal plows which turn on a common shaft and move the material toward a discharge opening. The retention time in the digester can be controlled by agitator speed, and the material depth in each stage can be varied by adjusting the individual plow angles. The influent raw material is conveyed to the top of the digester into the first stage; it goes through decomposition in the other seven stages and is discharged off the bottom. The material is intermixed and reseeded as it flows from stage to stage. In the first four stages it reaches a high temperature of about 120°F, while in the bottom four stages the material covers a temperature range of about 120 to 180°F.

To accomplish reseeding, a small amount of material from the preceding stage is plowed into and mixed with a substantial amount of older material in the stage below. In other words, a small amount of material from stage 1 is discharged into the mass of stage 2 while some of stage 2 material is mixed with stage 3 material, and so on down the stages until the material is discharged.

In this experiment, an inspection of the Pearl River waste in the top four stages after one day's time indicated that the initial moisture content had risen to over 65 per cent and that the material was wet, lumpy, and had a high degree of compactness. The experiment was continued using dry compost to reduce the moisture content in the top four stages. The moisture content of material in the first three stages was maintained near 50 to 55 per cent. The composting cycle was established at about 60 hr with material reaching a maximum temperature of about 140°F. Mechanical problems prevented further experiments. The following observations were made:

1. The continuous movement of this type material by the plows is not satis-

factory, especially in the early stages when water is formed in the decomposition of the waste. The material quickly "balls-up" and then becomes anaerobic. This "balling-up" action causes mechanical problems with the plows. Increasing the amount of dry compost or dry foreign material mixed with the influent material will increase the cost substantially. The beneficial effect of continuous plowing was not confirmed.

2. The seeding and reseeding procedure of this method does not appear suitable for this waste. It later developed from other pilot-plant work that the exact opposite seeding program to that described above is desirable for this waste. It is preferable to use a small amount of older material to seed a substantial amount of fresh material.

3. Due to the characteristics of this waste, material handling in its conveyance to and through the digester was a definite problem. This waste is so sticky, wet, and dense that the University's digester could not handle it without developing excessively high and mechanical torques.

Table III is a summary of the results of this experiment.

TABLE III.—Results of Tests Run in Michigan State University Digester Using Lederle Laboratories Waste

Stage Number	Approximate Age (days)	Temperature Range (°F)	COD (mg/25 g dry sample)
1	½	60– 90	12.0
2	1	90–115	—
4	2	130–140	—
6	3	80–100	8.8

Plant Practice

The experience gained in these studies prompted a decision to dispose of the Pearl River sludges by composting in an open sanitary landfill property then serving the plant for refuse disposal. However, since there is a seasonal market in the sale of compost and since there is a substantial amount of inexpensive land available, the short six-day process was not a prime requirement. Therefore, the pilot-plant short-term process was modified to a full-scale shredding and windrow process covering a period of about 150 days. A 10-acre plot was converted for this use in 1955 and large-scale equipment installed. This consisted of a 30 cu yd/hr shredder and a one cu yd capacity front-end loader.

An economic evaluation of the selected procedure indicated that the Multi-Stage method was practical and economical if a sufficient market could be found for the finished product to defray a part of the operating costs and to keep the compost from accumulating on the premises.

The sludge dewatered at the treatment plant on the afternoon and midnight shifts is trucked to the composting site and dumped on a prepared bed of sawdust and animal manures. The total sawdust and other wastes are proportioned to the sludge to give the desired blend. Seeding from the previous day's batch is done by moving some of the one-day old material to the fresh batch with the tractor. After the sludge has been discharged, the mixing and blending of all the ingredients are done with the tractor by picking up material from the outer edges and making a new cone-shape pile next to it, similar to the procedure used for mixing sand, gravel, and cement. About one part finely ground rock phosphate is added for each 200 parts of the fresh mixture.

To complete the blending, the mass of material is then bucketed through the shredder and piled in a long windrow next to the previous day's batch. The windrows are about 25 ft wide and as much as 15 ft in height, running a distance of about 300 ft.

Periodically the masses are sampled for pH, moisture content, temperature,

and COD. The windrows are allowed to compost for a period of about five months, after which the entire windrow is turned over and moved by truck to a different location. This material is called "crude compost," since it has gone through the high temperature range and has dried out into large hard lumps. Small cone-shape piles of crude compost are made to permit additional drying. During dry weather this material is trucked inside a high roof building which holds about 1,000 tons of compost, representing about one-half year's production. Here the crude material is re-shredded to a fine particle size, and to a moisture content of about 40 per cent. In final form it is a granular, free-flowing, dark brown material, with a slight humus odor. The finished compost is used on Lederle's grounds, by the nearby communities, and it is sold through a local dealer mainly for lawn treatment and soil conditioning.

Summary

Evaluation of some composting methods has been undertaken during the past four years at Lederle Laboratories, Pearl River, New York. The experience gained in these studies prompted a decision to dispose of the organic sludges by composting in an open sanitary landfill property using a modified multi-stage procedure. In the past 3 yr from 6 to 10 tons per day of organic sludges, originating from fermentation of antibiotics, extraction of pharmaceuticals from animal livers, stabling of animals, and the sanitary sewage from about 4,000 employees have been disposed of by this composting method. Composting has been the best and most practical method of treatment, disposal, and utilization of these wastes.

References

1. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
2. Snell, J. R., "Preliminary Report on High-Rate Composting Research." Civil and San. Engr. Dept., Michigan State Univ., E. Lansing, Mich. (July 1954).
3. Snell, J. R., "Some Engineering Aspects of High-Rate Composting." *Jour. San. Eng. Div.*, Amer. Soc. Civil Engrs., **83**, SA1, 1178 (1957).

ENGINEERS WANTED AT FORT MEADE

Sanitary, mechanical, and electrical engineers are needed for water and sewage treatment, utilities work, heating, electrical power and/or rates evaluation. Applicants should possess a degree in engineering and have had three or more years of experience in their respective fields. Beginning salary is $7510 and $8810 per annum. The work is interesting and is done in a congenial office. Retirement is provided, as is liberal leave and other fringe benefits. Apply, Civilian Personnel Office, Fort George G. Meade, Maryland (located midway and within commuting distance from Baltimore or Washington, D. C.).

DESIGN DATA FOR COMPLETELY-MIXED ACTIVATED SLUDGE TREATMENT *

By Vernon T. Stack, Jr.† and Richard A. Conway

Group Leader, and Sanitary Engineer, Union Carbide Chemicals Company, South Charleston, W. Va.

Since the activated sludge process, in comparison with other methods, requires the most exacting data for design purposes, the great variations in strength and treatment characteristics of industrial wastes prevent the application of "rule-of-thumb" design. For successful design, reasonable answers must be provided to the questions: What is the most economic aeration period? How much oxygen will be required? and What rate of oxygen transfer will be necessary? With this information available, an activated sludge system can be designed to accomplish the desired treatment, including a known amount of reserve capacity.

The procedure through which design data are obtained and the size of the apparatus to use are problems to the investigator. The apparatus must simulate the treatment process to be built. The procedure must permit the collection of data that can be confidently applied to full-scale design. Confidence in the design data is usually related directly to the size of the apparatus, and there is good reason for this attitude. Naturally, the most confidence can be placed in data obtained with full-scale equipment. As a compromise, most investigators rely on design data from pilot-scale apparatus. However, this approach may not be necessary. The bench-scale approach offered here has many advantages over larger-scaled equipment.

* Presented at the 134th Meeting, American Chemical Society; Chicago, Ill.; Sept. 7–12, 1958.

† At present, Director, Consulting Division, Roy F. Weston, Inc., Newtown Square, Pa.

Type of Activated Sludge Process

When compared with the flow-through principle of aeration tank design, the complete mixing approach has several advantages when applied to treatment of industrial wastes:

1. The wastes are distributed into the entire volume of the tank which, in addition to dilution, provides equal feeding to all parts of the tank. Under these conditions the greatest amount of work can be accomplished in a given aeration volume.

2. The BOD level in the aeration basin is essentially equal to the effluent BOD. Therefore, the biological culture is not subjected to appreciably stronger wastes for a significant period of time.

3. Lysis in the biological culture releases nutrient materials. In the homogeneously-mixed system, this release and the demand for nutrients occur at the same point. Therefore, if addition of nutrients is necessary, the possibility for reuse in the homogenously-mixed system will minimize those additions.

The use of a homogeneously-mixed aeration basin raises the question of short-circuiting of organic material. Short-circuiting definitely can occur, and Figure 1 presents the theoretical degree of short-circuiting in an infinitely-mixed system. Theoretically, nine per cent of the solute present in a completely-mixed system can be displaced in one-tenth of a period of time equivalent to the detention period, V/Q, where V is the mixed volume and Q is the hydraulic additions. Fortu-

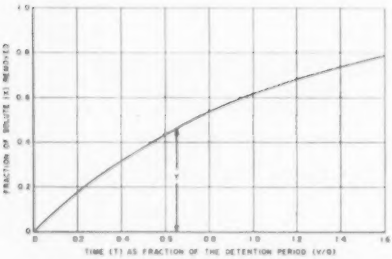

FIGURE 1.—Displacement of solute from a homogeneously-mixed solution by a continuous addition of solvent. $Y = X(1 - 10^{-0.412T})$, where T is fraction of V/Q, Y = Fraction of X removed in period of time T, X = Total quantity of solute present at $T = 0$, V = Volume of the system, and Q = Rate of addition of solvent.

nately, the completely-mixed, activated sludge system adsorbs organic material quickly. Therefore, loss of organic material to the effluent by liquid short-circuiting is minimized.

Apparatus

The bench-scale apparatus, tailored to homogeneous mixing, was based on the principle of the oxy-utilometer developed by Sawyer and Nichols (1). The major alteration was the adaptation of the aeration tube to continuous feeding. Thus, the apparatus has been named the continuously-fed oxygen utilometer. Figure 2 illustrates the assembled equipment, the components of which are readily available. The aeration mixture is contained in the resin kettle. Application of feed through the feed funnel displaces an equal volume of aeration mixture. The displaced volume passes upward through a clarification tube in which a sludge blanket exists. Therefore, the material that discharges through the liquid seal is clarified effluent. The clarification tube should be sized to the feed rate to limit the overflow rate.

Oxygen is supplied to the aeration mixture by recirculating about 1.5 liters of air per minute per liter of aeration volume. A 12-mm, fritted glass, diffuser tube is used for dispersion of the air. The air is scrubbed through sulfuric acid to remove basic components and through sodium hydroxide to remove acidic components,

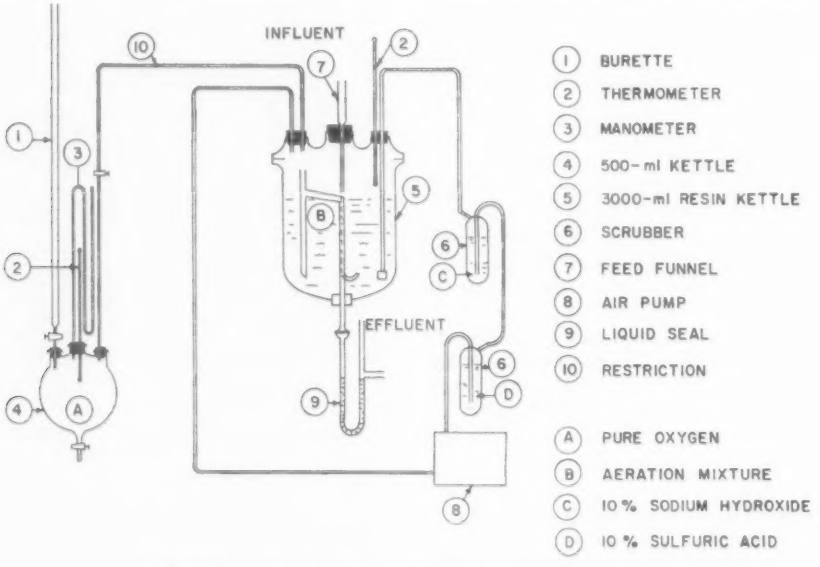

FIGURE 2.—Details of continuously-fed oxygen utilometer.

particularly carbon dioxide. The sulfuric acid scrubber is not required if basic components are absent.

The oxygen reservoir and fittings are necessary for replacement of oxygen utilized by biological activity. The restriction in the connecting line between the oxygen reservoir and the resin kettle minimizes diffusion between the oxygen and air. The burette permits the introduction of water to displace oxygen into the resin kettle. The manometer permits a comparison of atmospheric pressure to the pressure in the system.

Experimental Observations

Use of the continuously-fed oxygen utilometer for development of design data assumes that previous studies have established the feasibility of activated sludge treatment. Thus, the starting point of this discussion assumes that an activated sludge growth has been developed previously. The goal of the experimental observations is to obtain this information: oxygen requirements in terms of amount and rate of demand, BOD removal, and production of volatile solids.

Rate of Oxygen Demand

The continuously-fed oxygen utilometer is designed to determine the rate of oxygen demand directly. The one prerequisite is that the aeration mixture must be in equilibrium with the food supply. Equilibrium is achieved by constant feeding of the system at the desired feed rate. The period of time depends on the previous history of the activated sludge present, but at equilibrium the rate of increase in the volatile solids in the aeration mixture should be constant and relatively low.

During the equilibration period, the aeration mixture can be aerated from an external air source. At equilibrium, the system is closed and the amount of oxygen uptake is observed over a period of several hours. Data similar to those in Figure 3 will be obtained.

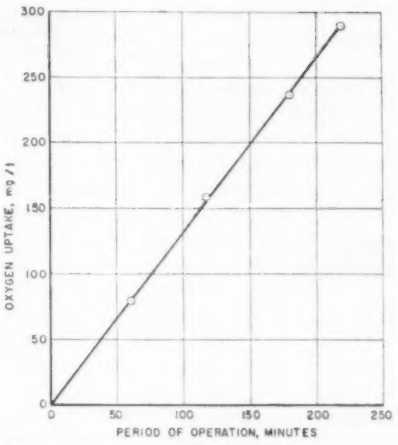

FIGURE 3.—Oxygen uptake as observed with the utilometer.

If the system is at equilibrium, the data will plot on a straight line. The slope of the plot is the rate of oxygen uptake. The rate in Figure 3 is about 80 mg oxygen per liter per hour.

At the suggested aeration rate in the continuously-fed oxygen utilometer, the rate of oxygen transfer does not usually limit the rate of oxygen uptake, but the presence of any material which decreases surface tension can decrease oxygen transfer. Therefore, an apparatus similar to that sketched in Figure 4 (or a simpler aeration tube) can be used to examine oxygen transfer. Data are obtained by sparging nitrogen through the sample until the oxygen concentration is essentially zero. The sample is then aerated at a constant rate, and the concentration of dissolved oxygen is determined to define curves as illustrated in Figure 5. Uniformity of sample handling must be maintained. A one-per cent solution of potassium chloride in distilled water may be used as the standard. If oxygen transfer into the industrial waste is appreciably less than that observed for the standard, the observed rates of oxygen transfer must be considered when designing aeration equipment.

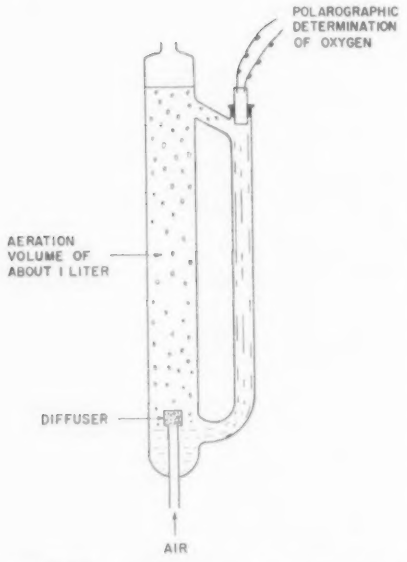

FIGURE 4.—Apparatus for measurement of oxygen transfer.

Quantity of Oxygen Required

The amount of oxygen required by a biological oxidation system is most conveniently expressed in terms of the work accomplished. Hence, a convenient relationship is pounds of oxygen required per pound of COD or BOD removed. In these studies, use of COD removed is convenient and is essentially equal to ultimate BOD removed. This condition is true because in the utilometer loss of organic material due to volatilization is small. Therefore, COD differences and BOD differences measure the same removals of material.

The oxygen requirement is constant for a system that is in equilibrium with a constant food supply. If the type of food supply or rate of food application is changed, the oxygen requirement may change. The net result depends on how much of the food supply is oxidized and how much is synthesized to sludge.

The COD removed is determined by analysis of filtered samples of the effluent and aeration mixture and a clarified sample of the feed. The net COD balance related to oxygen uptake for a particular run defines oxygen demand.

Quantity of Sludge Produced

Under certain conditions a carefully determined solids balance can indicate solids production during a definite period of operation of the utilometer. Characteristics of the waste must be constant if this approach is to be workable. If the strength and content of the wastes are variable, sludge production will vary, and a large amount of data will be needed to define an average. If these conditions occur, calculation of sludge production is suggested as follows:

organic material removed = organic material oxidized + organic material synthesized to sludge.

This relationship is true, but it refers to the fate of organic material that is removed rather than to the balance of reactions in the aeration mixture. In the aeration mixture, part of the existing biological sludge will be biologically oxidized. Thus,

organic material removed + sludge oxidized = oxygen uptake + synthesis.

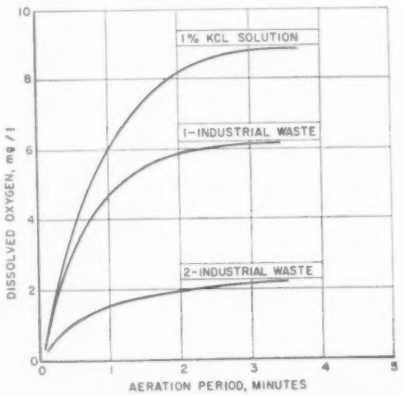

FIGURE 5.—Examples of oxygen transfer data obtained with laboratory apparatus.

By rearrangement,

total synthesis = organic material removed + sludge oxidized − oxygen uptake.

Therefore, the net amount of synthesis is expressed by

total synthesis − sludge oxidized = organic material removed − oxygen uptake.

Therefore, the net production of sludge can be calculated from data obtained with the utilometer. Sludge to be wasted can be estimated by a solids balance around the aeration mixture. A solids balance would account for solids in the clarified feed and the clarified effluent as well as sludge.

Recommended Experimental Procedure

The basic objective of the experimental procedure is to define how an activated sludge unit may be designed to handle the important variables and obtain a specified performance. A variation of detention time will be accompanied by variable effects of other variables, including final performance. The continuously-fed oxygen utilometer can be operated as a prototype apparatus, and performance can be observed at various detention times. This apparatus permits the collection of design data more quickly than can be accomplished by trying to evaluate the important variables independently. This following procedure is recommended:

1. Equilibrate a culture of activated sludge to the waste at a particular detention period. To begin the experimental evaluation, select the detention period in hours by dividing the average BOD of the waste in mg/l by 40. This approximation assumes that about 60 per cent of the BOD removed will be oxidized and that an oxygen uptake rate of about 25 mg/l/hr is minimum.

2. Composite the feed samples over a period equal to the detention period being studied in the utilometer. This will account for variations in the characteristics of the waste.

3. At the selected detention period, feed the composites in the order that they were collected. For a period during the feeding of each composite, determine: (a) the quantity and rate of oxygen uptake; (b) the COD of the feed, of the aeration volume, and of the effluent; and (c) the suspended solids in the aeration mixture (see Appendix). BOD values for the feed and effluent should be taken to establish the efficiency of BOD removal. A number of composites should be examined to establish limits in performance data.

4. When results have been established at one detention period, decrease the detention period by increasing the feed rate. Collect a new set of data at the new detention period.

5. Continue to decrease the detention period until the activated sludge system becomes overloaded. Overload is usually apparent as a decrease in the efficiency of BOD or COD removal or as a very turbid effluent from the system.

Interpretation of Results

Synthetic Waste

The relationship of data obtained with the utilometer can be better understood through results from treatment of a simple waste. The data in Figure 6 were obtained by treating a dextrose solution. An extended range of detention periods was employed to show the balance between design factors. At long detention periods, with the system lightly loaded with organic material, oxygen consumed per unit of COD removed was relatively high, while sludge production was low. This relationship shows the normal balance in the oxidation-synthesis reactions. The long detention period permitted a significant amount of sludge oxidation. Thus, the

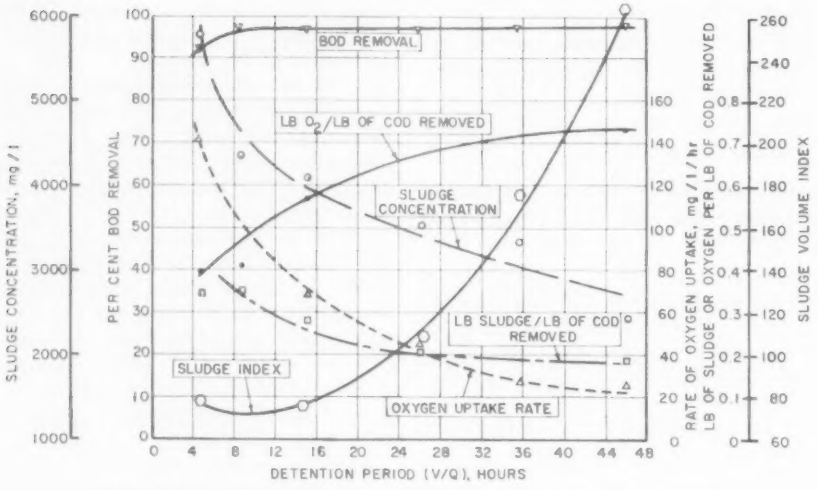
SLUDGE CONCENTRATION, mg/l
PER CENT BOD REMOVAL
RATE OF OXYGEN UPTAKE, mg/l/hr
LB OF SLUDGE OR OXYGEN PER LB OF COD REMOVED
SLUDGE VOLUME INDEX
DETENTION PERIOD (V/Q), HOURS
BOD REMOVAL
LB O2/LB OF COD REMOVED
SLUDGE CONCENTRATION
LB SLUDGE/LB OF COD REMOVED
SLUDGE INDEX
OXYGEN UPTAKE RATE

FIGURE 6.—Utilometer data using 1,500 mg/l dextrose as waste.

net result was a large amount of oxidation and a low production of sludge. As the detention period was shortened, the amount of work accomplished per unit volume of aeration capacity increased. The amount of sludge oxidation became less significant, and the net result was more sludge production and less oxygen consumption per unit of COD removed.

Oxygen uptake rates and BOD removals reflected the organic load applied to the system. The decline in BOD removal at detention periods less than about 8 hr showed capacity loading for the system. As the organic load to the system was increased through higher feed rates, oxygen uptake rates increased in proportion to the food supply.

The results from experimental determination of the balance of oxygen consumption and sludge production versus COD removed are in reasonable agreement with theory:

$$\frac{\text{wt. } O_2 \text{ utilized}}{\text{wt. COD removed}} + 1.42 \frac{\text{wt. volatile sludge produced}}{\text{wt. COD removed}} = 1.$$

The agreement suggests that calculation of sludge production is practical.

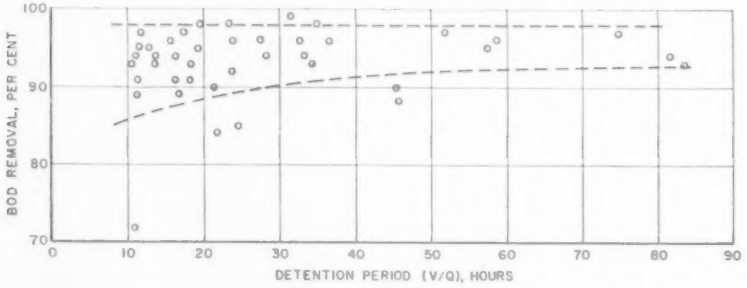

FIGURE 7.—Treatment efficiency for organic chemical waste as indicated by the utilometer.

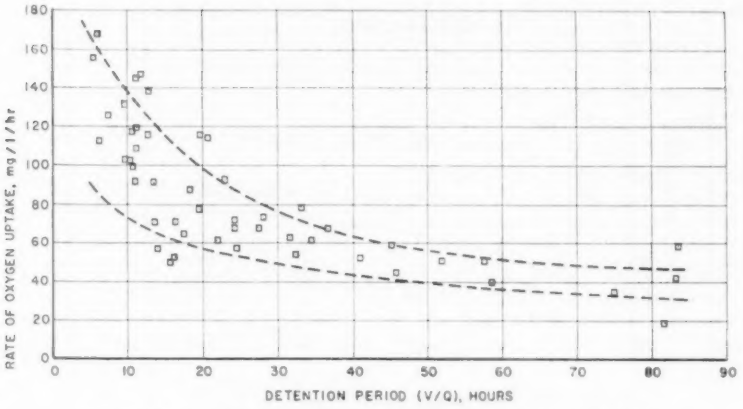

FIGURE 8.—Rate of oxygen demand of organic chemical waste.

Weston and Eckenfelder (2) determined the ultimate BOD of cell material to be 1.42 g/g. This factor converts sludge to oxygen equivalent.

At longer detention periods, suspended solids in the effluent were low, but the sludge volume index was high. As the system was more heavily loaded with organic material, the sludge volume index improved. With detention periods less than about 4 hr, the biological growth was mostly in the logarithmic phase. Hence, the growth became dispersed and the system failed.

Results obtained with the synthetic feed show expected performance characteristics. Similar relationships can be established for any organic waste that is amenable to biological treatment.

An Industrial Waste

The continuously-fed oxygen utilometer was used to determine design

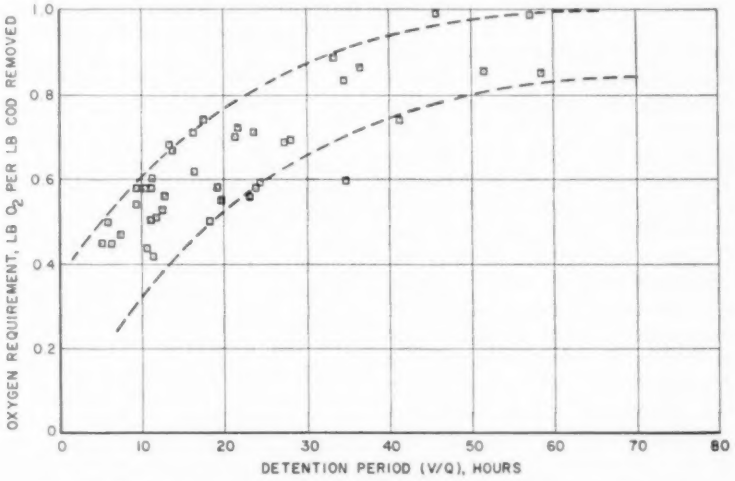

FIGURE 9.—Oxygen requirement for biological treatment of organic chemical waste.

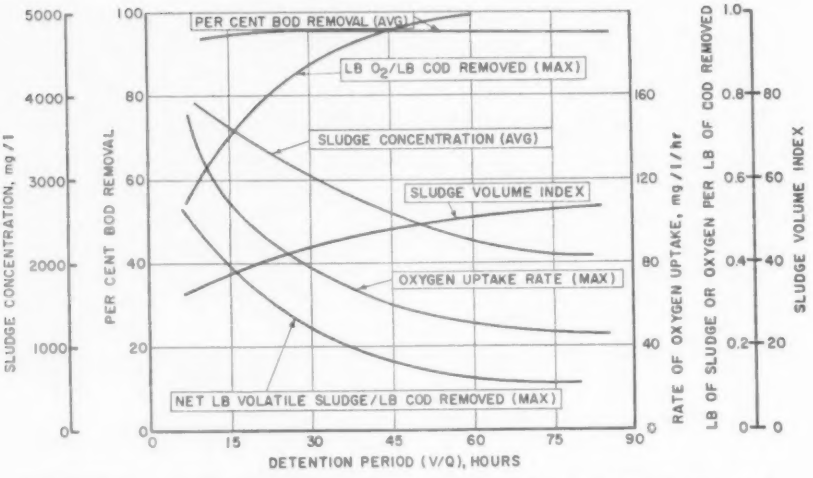
PER CENT BOD REMOVAL (AVG)
LB O_2/LB COD REMOVED (MAX)
SLUDGE CONCENTRATION (AVG)
SLUDGE VOLUME INDEX
OXYGEN UPTAKE RATE (MAX)
NET LB VOLATILE SLUDGE/LB COD REMOVED (MAX)
SLUDGE CONCENTRATION, mg/l
PER CENT BOD REMOVAL
RATE OF OXYGEN UPTAKE, mg/l/hr
LB OF SLUDGE OR OXYGEN PER LB OF COD REMOVED
SLUDGE VOLUME INDEX
DETENTION PERIOD (V/Q), HOURS

FIGURE 10.—Development of design factors for activated sludge treatment of organic chemical waste.

data for an activated sludge unit for a large chemical plant. The wastes discharged varied in BOD strength and types of organics. At times, the wastes were biostatic to a degree. Under these conditions, performance of the activated sludge process can be expected to vary from day to day. This variation is an important consideration in the selection of design factors.

Figures 7, 8, and 9 show the degree of variation in the results. The spread in the results illustrates the effect that variations in the characteristics of the waste have on performance of the activated sludge process. At the same time, the trend in the data shows the same relationships previously illustrated with the dextrose waste. Interpretation of the data for design purposes is shown in Figure 10. The curves express the results as they should be used for design purposes.

Net production of sludge was calculated by utilizing the curve in Figure 9 for minimum oxygen demand. Calculation was based on the relationship previously discussed, which may be expressed as

$$\frac{\text{wt. volatile sludge produced}}{\text{wt. COD removed}} = \frac{1 - \text{wt. oxygen demand of COD removed}}{1.42}.$$

The calculated curve represents the expected maximum production of sludge. This calculation could be refined further by predicting the quantity of sludge to be wasted:

sludge wasted = sludge produced − sludge discharged in the effluent.

Any of the detention periods in Figure 10 could be selected for design purposes. However, the one selected must depend on the particular situation for the waste disposal problem. If the waste volume is small, work performed by the aeration volume may be sacrificed to get less sludge production and a process that requires less attention. If the detention period is long enough, sludge to be wasted will be negligible because losses in the effluent will equal sludge production.

Under conditions where the volume of waste is large, economical construction and operation of the activated

sludge process may require that the process be heavily loaded. Hence, the shortest practical detention period may be desired. One set of data not shown in Figure 10 is important in this decision. At higher BOD loadings, the quantity of suspended solids in the effluent increases significantly since the activity of the culture approaches a logarithmic growth rate. For the industrial waste studied, high turbidity in the effluent was evident at detention periods of less than 15 hr. Therefore, a minimum detention period of 15 hr was selected.

At a 15-hr detention period, the design factors are defined as: an oxygen uptake rate of 110 mg/l/hr, an oxygen demand of 0.7 lb per lb of COD removed, and a net sludge production of not more than 0.4 lb per lb of COD removed. When obtained by the procedure described, the scale of the equipment should not limit the usefulness of the data.

Summary

A continuously-fed oxygen utilometer, which can be utilized to determine design data for the completely-mixed activated sludge process, has been developed. Careful use of the apparatus and procedure permits the development of design data in terms of rate of oxygen uptake, oxygen demand, sludge production, and per cent BOD removal. The fact that the apparatus is bench-scale is not a serious hindrance to the use of the data for design purposes.

References

1. Sawyer, C. N., and Nichols, M. S., "Activated Sludge Oxidations. I. Effect of Sludge Concentration and Temperature upon Oxygen Utilization." *Sewage Works Jour.*, **11**, 1, 51 (Jan. 1939).
2. Weston, R. F., and Eckenfelder, W. W., "Application of Biological Treatment to Industrial Wastes. I. Kinetics and Equilibria of Oxidative Treatment." THIS JOURNAL, **27**, 7, 802 (July 1955).

APPENDIX

Operational Procedure

The data obtained from the continuously-fed oxygen utilometer must define the balance of biological activity in the system.

Preparation of the Utilometer for a Run (See Figure 2)

1. Remove the aeration mixture.
2. Clean thoroughly all surfaces in the equipment that contact the aeration mixture.
3. Replace the caustic and acid in the scrubbers. This should be done frequently.
4. Remove a sample for COD analysis. Record the volume of the aeration mixture to be returned to the aeration kettle.
5. Replace the aeration mixture and supply air from an external source with the system open to the atmosphere.
6. Fill the oxygen reservoir with oxygen and permit the oxygen to come to room temperature.

Collection of Data

1. Start the feed, and as soon as effluent is being discharged through the liquid seal, remove the external air supply and start the air pump. If the feed rate is slow, distilled water may be added to the aeration mixture to replace the liquid volume removed for COD analysis. This will eliminate a long waiting period.
2. Make sure that the oxygen reservoir is at atmospheric pressure.
3. Close the system and open the stopcock between the oxygen reservoir and the resin kettle. Record immediately the temperature in the system and atmospheric pressure.
4. As oxygen is utilized, the pressure in the system will decrease. Add water from the burette to adjust pressure

in the system until it is equal to atmospheric pressure.

5. Periodically record the total volume of water added. Also record temperature in the system and atmospheric pressure.

6. Throughout the run, collect the total effluent discharged. Compare volume discharged with volume fed to make sure that volume in the resin kettle has not changed.

7. After operation of the equipment for a period which defines the amount and rate of oxygen uptake (preferably about 3 hr), open the system to the atmosphere and supply air from an external source.

8. Determine suspended solids in the aeration mixture. Determine COD on filtrate from a sample of aeration mixture.

9. Determine COD and BOD values of the feed and a filtered sample of the effluent.

10. Determine suspended solids in the clarified feed and the effluent.

11. Calculate oxygen utilized.

12. Other determinations can be made, such as: ORP, SVI, or chlorine demand.

MEETINGS OF INTEREST

Oct. 11–16 **American Society for Testing Materials,** Sheraton-Palace Hotel, San Francisco, Calif. ASTM, 1916 Race Street, Philadelphia 3, Pa.

Oct. 11–16 **American Institute of Electrical Engineers,** Hotel Morrison, Chicago, Ill. Raymond C. Mayer & Associates, 51 East 42nd Street, New York 17, N. Y.

Oct. 19–23 **American Public Health Association,** Annual Meeting, Convention Hall, Altantic City, N. J. Dr. Berwyn F. Mattison, Executive Secretary, APHA, 1790 Broadway, New York, N. Y.

Oct. 19–23 **American Society of Civil Engineers,** Annual Convention, Statler Hilton Hotel, Washington, D. C. W. H. Wisely, Executive Secretary, ASCE, 33 W. 39th Street, New York 18, N. Y.

Oct. 19–23 **National Safety Council,** Conrad Hilton Hotel, Chicago, Ill. National Safety Council, 425 N. Michigan Avenue, Chicago 11, Ill.

Oct. 20–22 **National Conference on Standards,** American Standards Association, Sheraton-Cadillac Hotel, Detroit, Mich.

Oct. 25–27 **National Association of Municipal Utilities,** Town House Hotel, Kansas City, Kans. A. D. McGuire, P. O. Box 99, Overland Park, Kans.

Oct. 27 **Association of Consulting Chemists and Chemical Engineers,** Annual Symposium and Banquet, Shelburne Hotel, New York, N. Y.

Nov. 29–Dec. 2 **American Municipal Association,** Brown Palace Hotel, Denver, Colo. Patrick Healy, Jr., Executive Director, 1612 K Street, N. W., Washington 6, D. C.

Nov. 29–Dec. 4 **American Society of Mechanical Engineers,** Chalfonte-Haddon Hall Hotel, Atlantic City, N. J. ASME, 29 West 39th Street, New York 18, N. Y.

Dec. 1–2 **North American Pulp, Paper, and Paperboard Industrial Wastes Conference,** Edgewater Beach Hotel, Chicago, Ill. Russell L. Winget, Executive Secretary, National Council for Stream Improvement, Inc., 271 Madison Avenue, New York 16, N. Y.

RADIOISOTOPE WASTES HANDLING *

By H. Gladys Swope

Senior Chemist, Chemical Engineering Division, Argonne National Laboratory, Lemont, Ill.

Since 1953 the number of industrial plants using radioisotopes in the United States has increased three times and the total curies of radioactivity distributed in the same period has multiplied 18 times. By November 30, 1958, 1,463 industrial organizations had been authorized to use radioisotopes for industrial purposes (1). By July 1959 this number had increased to about 2,000. Present indications are that this growth will continue for some time. While much of the present utilization results from industrial radiography, thickness gaging, and oil well logging, research and development are pointing the way to additional applications.

It is inconceivable that sewage and industrial wastes handling will remain untouched by this utilization of atomic energy for industrial development, even though the disposal of radioactive wastes is regulated by the Atomic Energy Commission. It is the impact of this growing giant on present procedures which will be discussed.

Of the three kinds of radioactive wastes (solids, liquids, and gases) this paper deals solely with liquid wastes.

Waste treatment in general is an unwanted problem. Sewage treatment does not, in many cases, get the attention it deserves until a community is faced with a river so polluted that it can no longer be used for recreational purposes or as a source of water supply to other communities downstream. Similarly industrial wastes are not usually adequately treated until the industry is forced to do so because of unsightly river conditions or because new regulations force compliance. This is due to the fact that both sewage and industrial waste treatment cost money and seemingly there is no return on the investment except in terms of public relations. There are, of course, exceptions to this rule. In the case of atomic energy applications, the Atomic Energy Commission regulates the disposal of radioactive wastes (2).

Definition of Radioactive Wastes

Much has been written in the public press about the magnitude of the waste disposal problem in atomic energy installations. Other liquid wastes are normally routed into the nearest drain. But no thinking individual would consider doing this with radioactive liquids any more than he would consider dumping gasoline into a sewer. The hazards are different but nonetheless they are hazards.

Before any industrial waste is discarded, two questions must be asked and answered: Is it hazardous to people or property? Is it valuable? Many industrial wastes are, or could be, valuable. Klassen (3) makes the following statement relative to atomic wastes: "Man-made atomic energy is a relatively new industry and, like all new industries, has new problems of disposing of its industrial wastes, or as I rather choose to call it, industrial residues, for they may not be wastes but products of reclaimable value."

Radioactive liquid wastes may be classified as high-level, medium-level, and low-level. High-level wastes are those in which activity is measured in thousands of curies; a curie being the amount of radioactivity equivalent to 2.2×10^{12} disintegrations per min-

* Presented at the Southwest Regional Meeting of the American Chemical Society and the Texas Water and Sanitation Research Foundation; San Antonio, Tex.; Dec. 4–6, 1958.

ute. These wastes come into being when uranium or plutonium is recovered from spent reactor fuel rods and, of course, require shielding and containment for radiation protection.

Intermediate wastes are those having activity some 10^3 to 10^5C below that of the high-level ones and they require some shielding. Low-level wastes are those from industries, hospitals, and research laboratories and their activity is measured in milli- or microcuries. These wastes come from the use of radioisotopes and are the ones which are of most interest to sewage and industrial wastes personnel.

Some Uses of Radioisotopes

Dr. Willard Libby of the Atomic Energy Commission *, speaking before the Second United Nations International Conference on Peaceful Uses of Atomic Energy in Geneva in September 1958, made the following statement:

> "The economic importance of radioisotopes is amply illustrated by the experience of American industry. We have estimated the tangible contributions of radioisotopes to the U. S. national economy from industrial uses as follows: in 1953, $100,000,000; in 1956, $400,000,000; and in 1957, $500,000,000 . . . and it appears reasonable to anticipate that the figures will soon total one billion dollars annually" (4).

Some of the specific uses of radioisotopes are described below.

If dynamite remains unexploded in drill holes it is a hazard. It has been found that the hazard may be reduced or eliminated if Sb^{124} (7 mc/250 lb explosive) is mixed with the dynamite constituents during manufacture, thus providing a means whereby the dynamite can easily be detected. In this case a radioisotope with a fairly short half-life was needed in order to avoid accumulation of radioactivity in stores and explosion sites. The radioisotope also had to be non-toxic in the atmosphere, compatible with the explosive, and insoluble in water. In addition the gamma ray energy was required to be high enough for easy detection. All of these properties were found in Sb^{124} which has a 60-day half-life and gamma ray energy of 1.7 and 0.6 Mev (5).

The radioisotope C^{14} is being used to measure fuel distribution in automobile engines (6). The performance of an automobile engine is noticeably limited by the failure of the intake system to supply equal amounts and qualities of fuel to all of the cylinders. It is desirable that such additives as tetraethyl lead, for example, be divided among the cylinders in such a way as to provide maximum effectiveness. If tetraethyl lead is tagged with C^{14} at a level of 0.5 mc/ml, it can be readily traced after addition to a fuel in a concentration of 3 ml/gal. When such a fuel is burned in an engine, the various concentrations of tetraethyl lead received by the separate cylinders can be determined by comparing the specific activities of the CO_2 in their combustion gases. These activities are measured in an ionization chamber of the continuous-current type.

Radioactive tracer methods have helped solve two problems in operating refinery catalytic-cracking units: (a) the mixing behavior of fluidized catalyst, and (b) deactivation of fresh catalyst (7). Any one of the three isotopes (Ce^{144}, Cr^{51}, or Sc^{46}) is adsorbed strongly onto the surface of either fresh or equilibrium silica-alumina cracking catalyst from a somewhat acidic aqueous solution of the trichlorides. The tagged catalyst, after drying, shows no loss of radioactivity after 2 hr heating in air at 1,000°C and the adsorbed isotopes are not volatile under high temperature conditions. The known chemistry of cerium, chromium, and scandium indicates that the free metals and their oxides, hydrides, nitrides, carbides, and carbonyls would be non-volatile under conditions of use in commercial units. With Sc^{46} in solution at a pH of 4,

* Resigned from the Commission June 30, 1959.

distribution is essentially perfect. One millicurie of Sc^{46} uniformly mixed in 500 tons of catalyst is all that is required. Sc^{46} has a half-life of 85 days and a 0.89 and 1.12 Mev gamma.

The use of radioisotopes is not only a money-saving device, but in many cases, their use makes possible an operation, test, or knowledge which can be obtained in no other way. A leak-testing device (8), using the radioisotope Cs^{134} to find leaks in repeater amplifiers of a transatlantic voice cable, has been developed. The requirement here was that the radioisotope have a short half-life, be a high hard gamma emitter, and be cheap. Cs^{134} has a half-life of 2.3 yr, a 2 Mev gamma, and costs $1 per mc. To pull up a repeater in a transatlantic voice cable would have cost a quarter of a million dollars!

Another unusual use of radioisotopes is the testing of home laundering procedures by the use of C^{14} (9).

The subject of the various uses which can be made of radioisotopes is a fascinating one. And because of this fascination, it is hard for most people to become interested in one of the inevitable by-products of their use, namely the wastes. But wastes accumulate and they must be handled.

Radioisotope Waste Disposal

Atomic Energy Commission Requirements

Individuals or organizations desiring to use radioactive materials are required to obtain a license except in instances where only tracer quantities of certain isotopes are used. In order to obtain a license, it is necessary to furnish information with respect to the use to be made of the isotope and the method of disposal to be used. These regulations are set forth in Parts 20 and 30 of the U. S. Code of Federal Regulations (2). The license is obtained by writing to the Division of Licensing and Regulation, Atomic Energy Commission, Washington 25, D. C.

It is possible to obtain microcurie quantities of 65 isotopes from commercial organizations which have been licensed by the Commission. The amounts available range from 0.1 μc of Sr^{90}, Y^{90}, and Po^{210} to 250 μc quantities of tritium. The others are available either in 1, 10, or 50 μc lots. Records must be kept by the commercial firms selling these tracer quantities so that the Commission is fully informed at all times on how and to whom they have been distributed.

Methods of Disposal of Radioisotopes

What happens to these radioisotopes after they have served their purpose? Many of them, of course, have decayed to safe levels by the time the experiment is concluded. For example, As^{77} has a half-life of only 38 hr while I^{131} has an 8-day half-life. Others are incorporated in devices which are never disposed of, such as thickness gages. Ideally the isotope should be allowed to decay for completely safe disposal but in some cases this may be impracticable. For those isotopes which are ionized, mixed-bed ion-exchange columns are recommended. After passage of the liquid through a mixed-bed resin, the radioactivity will be retained on the resin. The mixed resins should be high-capacity ones. The cation resin should be a strongly acidic one of the polystyrene-divinylbenzene type, 8 to 10 per cent cross-linked, in the hydrogen form. The anion resin should be one of the strongly basic amine types, 8 per cent cross-linked, in the hydroxyl form. After exhaustion, which in the case of a mixed-bed exchanger could be roughly indicated by conductivity measurements of the effluent followed by an assay for radioactivity before disposing of the effluent, the resin may be disposed of either by storing and allowing the radioactivity to decay or by sending the resin to a radioactive waste disposal service company.

The above methods are recommended for schools, hospitals, and research lab-

oratories where only tracer quantities of radioisotopes are used.

Problems of Disposal of Radioisotopes

In some cases, however, the people who get tracer quantities of radioisotopes may not be as careful as they should be. If such materials are carelessly disposed of or accidentally thrown away, what happens then? Perhaps this problem can best be discussed in terms of a particular radioisotope, for example P^{32}, which has a half-life of 14.3 days and is used for many experiments in agriculture and in schools. According to the U. S. Code of Federal Regulations a person may obtain 10 μc from commercial organizations which are licensed to sell radioisotopes. It is permissible to discharge into a sewer or watercourse no more than 2×10^{-4} μc/ml.

A hypothetical example may be helpful in outlining some of the problems. For this, assume a community of 12,000 population in which a college, a hospital, and several small industries are located. Assume that the college had legally obtained 10μc of P^{32}, the hospital had on hand 100 μc, and one small industry had also 100 μc. Further assume that the community has a small sewage treatment plant which has a flow of 1.2 mgd and discharges its effluent into a stream, the water from which is used by the next community downstream as its source of water supply. Under these circumstances, would the accidental discharge of the total amount of P^{32} held by the aforementioned groups be hazardous to anyone?

On the basis of a flow of 1.2 mgd at the sewage plant (or 50,000 gph) and, with a 2-hr detention period in the settling tanks, it can be assumed that, even if all of the 210 μc of P^{32} were discharged at the same time, it would be mixed at the sewage treatment plant with 100,000 gal of sewage. On this basis, even if all of the 210 μc of P^{32} were retained in the effluent, there would be only 5.5×10^{-7} μc/ml in the effluent, a safety factor 36 times greater than that required by the U. S. Code of Federal Regulations, since it is permissible to discharge 2×10^{-4} μc/ml.

The above hypothetical example has been used for two reasons: (a) to show that a factor of safety has been written into the U. S. Code of Federal Regulations; and (b) to awake city, county, and state agencies to the fact that, if they have not already done so, they must be prepared to analyze for radioactivity. In the future this test may become as important in water works operation as bacteriological analyses and as important in sewage plants and on stream surveys as the biochemical oxygen demand determination.

Texas is aware of this problem as was pointed out in a paper on radioactivity in Texas streams by Drynan and Gloyna (10). In a panel discussion on the monitoring of stream water quality (11) one of the objectives was to determine background data on certain types of wastes, such as chlorides and radioactivity.

The USPHS had as its objective in 1958 the establishment of 50 water sampling stations on the Great Lakes and interstate streams of the U. S. Forty-four of these sampling stations are in operation; the other six are being planned. In addition to the usual analyses, total beta radioactivity is determined. Sampling stations are located on the Columbia, Missouri, Mississippi, Colorado, Rio Grande, Red, Arkansas, Tennessee, Savannah, Ohio, Delaware, Connecticut, and Merrimac Rivers, in addition to the Great Lakes.

Another group which is alert to the dangers of radioactivity is the Metropolitan Water District of Southern California at La Verne, California (11). Water samples from Lake Mead and Lake Havasu are examined monthly for both alpha and beta-gamma activity. Monthly composite samples of the raw and treated Colorado River

water are likewise assayed for radioactivity at the water treatment plant.

Factors Determining Disposal

The determining factors for radioactive waste disposal are volume, radioactivity level, pH, and amount of total and suspended solids. Perhaps a brief description of the methods used at the Argonne National Laboratory for handling liquid radioactive wastes would be of interest. These same methods may be used by any group which is faced with the problem of handling radioactive wastes from many research experiments.

Methods Used at Argonne

Radioactive wastes are segregated from non-radioactive wastes in order to keep the volume of the radioactive wastes to a minimum. In addition, as a factor of safety, all drains from laboratory experiments go to 1,500-gal retention tanks in order to catch any accidental spills of radioactivity. These are monitored when full and, if they contain radioactivity above tolerance, the contents are then trucked to the waste processing building for treatment.

Radioactive wastes are treated by filtration, flocculation, ion exchange, or by evaporation. If the waste contains a large amount of suspended matter, it is filtered through porous stone filters and the filtrate is then analyzed. If the beta-gamma activity has been low (up to 400 dpm/ml) and if the activity was adsorbed on the suspended matter, this is all the treatment the waste may require. However, this is very seldom the case as most radioactivity is in solution. When the dissolved solids are less than 1,000 mg/l, the waste is filtered and passed through a cation exchange column.

In cases where the waste has about the same amount of activity as above but in which the total solids are over 1,000 mg/l and the pH between 2 and 4, sodium hydroxide is added to the waste to obtain a pH of 13 and then the waste is flocculated. This process gives a decontamination factor of 10 to 20, depending on the particular radionuclides. For wastes which have a beta-gamma activity of around 10^4–10^6 dpm/ml and total solids greater than 1,000 mg/l, evaporation is used. Wastes are concentrated to 20-per cent solids in the evaporator and then these bottoms are further handled in a so-called concentrator, which is a steam-jacketed kettle operated under vacuum. The intention is to concentrate to such an extent that, on cooling, the bottoms will solidify. None of the processes described here require shielding for the particular wastes involved. The effluent, condensates, or filtrates are all assayed for radioactivity before allowing them to be discharged to the laboratory waste treatment plant. Here they mix with other laboratory wastewater and finally with the sewage treatment plant effluent and are again monitored. At this last point the maximum permissible limits for discharge into watercourses must be followed as given in Handbook 69 (12).

At Argonne National Laboratory, wastes are concentrated to the smallest possible volume, and, even at these concentrations, do not require shielding. All of the concentrated wastes are sent to Oak Ridge National Laboratory for burial.

Summary

In this paper no attempt has been made to cover the treatment of high-level or intermediate-level wastes from the reprocessing of spent reactor fuel rods, nor has the treatment of plutonium wastes been discussed. Instead the growth and magnitude of the versatile new tool, radioisotopes, have been described, together with some of the specific uses of radioisotopes. New waste problems have come into being for industry as a result of the use of radioisotopes and new problems have been created for the regulatory bodies,

even though the disposal of radioactivity is regulated by the Atomic Energy Commission. The methods used at the Argonne National Laboratory for the treatment of low-level radioactive wastes have been described briefly in the hope that this description will be helpful to others who are confronted with similar problems.

References

1. Twenty-Fifth Semi-Annual Report to Congress, Atomic Energy Commission. "Atomic Industrial Progress and Second World Conference." P. 67 (July–Dec. 1958). Supt. of Documents, U. S. Govt. Printing Office, Washington 25, D. C.
2. "Title 10—Atomic Energy." U. S. Code of Federal Regulations, Parts 20 and 30.
3. Klassen, C. W., "The Technical and Administrative Aspects of the Environmental Problems as Related to States." TID-7517 (Part 1B), 545 (Oct. 1956).
4. Libby, W. F., "Progress in the Use of Isotopes. The Atomic Triad-Reactors, Radioisotopes and Radiation." *Proc. 2nd United Nations Internat. Conf. on Peaceful Uses of Atomic Energy*, Geneva, Switzerland, **19**, 84 (Sept. 1958).
5. Eichholz, G. G., Smith, A. O., and Bauer, A., "Sb^{124} Marking for a Safer Dynamite." *Can. Mining and Met. Bull.*, **50**, 117 (Mar. 1957); *Nucleonics*, **15**, 11, 170 (Nov. 1957).
6. Cooper, D. E., "C^{14} Measures Fuel Distribution." *Nucleonics*, **15**, 6, 136 (June 1957).
7. Gunn, V. P., "Tracing Catalysts in Refinery Crackers." *Nucleonics*, **14**, 5, 69 (May 1956).
8. Editorial, "Bell Laboratory Tests Leaks with Cs^{134}." *Nucleonics*, **14**, 7, 82 (July 1956).
9. Ehrenkranz, F., and Jebe, E. H., "C^{14} Method Tests Home Laundering Procedures." *Nucleonics*, **14**, 3, 96 (Mar. 1956).
10. Drynan, W. R., and Gloyna, E. F., "Radioactivity in Texas Streams." 14th Southwest Regional Meeting, A.C.S. (Dec. 1958).
11. Panel Discussion, "Monitoring of Stream Water Quality." *Jour. Amer. Water Works Assn.*, **50**, 9, 1211 (Sept. 1958).
12. U. S. Dept. of Commerce, National Bureau of Standards Handbook 69, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Concentrations in Air and Water." Supt. of Documents, U. S. Govt. Printing Office, Washington 25, D. C.

PULP, PAPER, AND PAPERBOARD WASTE CONFERENCE

The first North American Pulp, Paper, and Paperboard Industrial Waste Conference is scheduled to be held at the Edgewater Beach Hotel in Chicago, Illinois, December 1–2, 1959. The Conference is being jointly sponsored by the National Council for Stream Improvement, Inc., Institute of Paper Chemistry, and the Sulphite Pulp Manufacturers' Research League.

The purpose of the Conference is to accomplish an exchange of all pertinent basic data relating to pulp and paper industry waste disposal on an inter-regional basis. The program will be devoted to the broad problems of stream sanitation and waste treatment and waste disposal applicable to all types of pulp and paper wastes.

General sessions will include the categories of: waste assimilative capacity, aquatic biology, solids removal and sludge dewatering, BOD reduction of strong spent pulping liquors, and BOD reduction of paper, paperboard, and weak pulping wastes.

For further information contact:

Mr. Russell L. Winget, Executive Secretary
National Council for Stream Improvement, Inc.
271 Madison Avenue
New York 16, N. Y.

Stream Pollution

LABORATORY STUDIES OF SEWAGE EFFECTS ON ATMOSPHERIC REAERATION *

By M. C. Rand

Chief Chemist, Middlesex County Sewerage Authority, Sayreville, N. J.

In 1938 it was reported that domestic sewage, even in small concentrations, produced a decided reduction in the rate of surface reaeration of water (1). Certain recent publications (2) (3) present results of the same order of magnitude. However, the studies described herein indicate that under somewhat different conditions the effect of domestic sewage is not nearly so great.

Apparatus for Controlled Mixing

The experiments in which the reaerating liquid was stirred utilized the apparatus shown in Figures 1 and 2. The liquid samples were contained in 6 lucite cylinders, 6 in. in diameter by 4½ ft in height, with flat lucite bottoms cemented in place. Centered inside each cylinder, a lucite tube 3½ in. in diameter extended from a level 1 in. above the bottom to a level 3 ft, 11 in. above the bottom. The purpose of the center tubes was to permit fairly exact knowledge of both the path of travel and the rate of travel of the circulating water. Without them, there was a marked tendency toward localized circulation around the impeller blades, so that the effective rate of travel from top to bottom of a cylinder was indefinite. The impellers extended 9 in. into the tops of the inner tubes. Their rotation rate was adjusted by means of a variable-speed transmission mounted directly on the motor, and by changing the pulley mounted on the horizontal shaft at the top of the apparatus. In operation, each cylinder was filled to a depth of 4 ft, 2 in., which required a volume of approximately 20.9 l.

Prevention of Biological Oxidation

It was considered preferable to prevent the biological utilization of dissolved oxygen, rather than to attempt to measure and correct for its effect. This decision was based on a number of factors. One of the most important was that in many of the experiments,

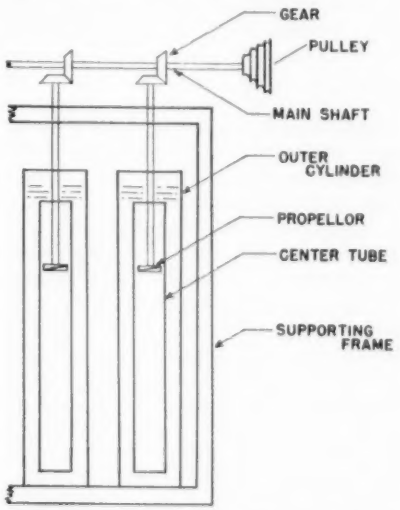

FIGURE 1.—Representative section of apparatus used in laboratory reaeration experiments.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J.

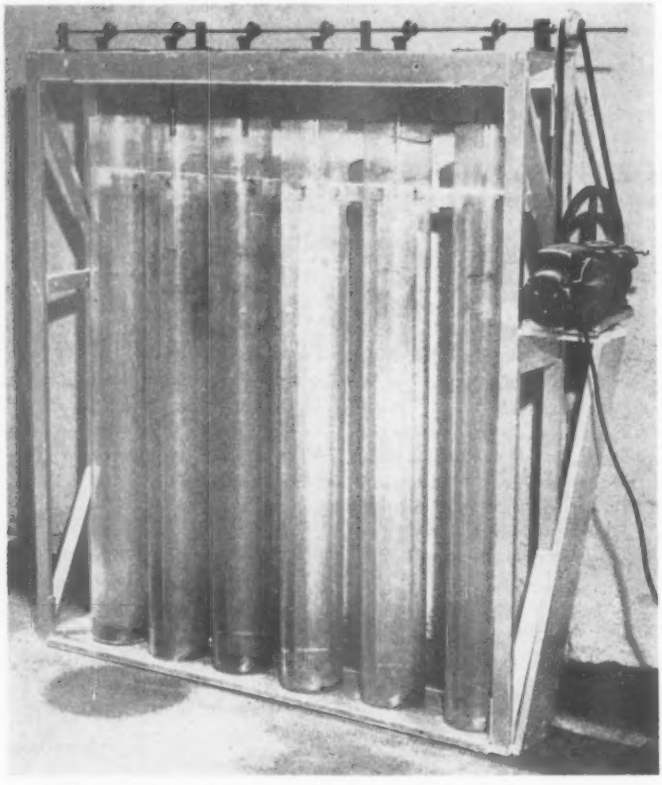

FIGURE 2.—General view of laboratory reaeration apparatus.

uninhibited biological oxidation would have removed dissolved oxygen from the system more rapidly than reaeration would have replaced it.

In the work with tap water, mercuric chloride was added to give a final concentration of 20 mg/l. This concentration proved adequate for the control of any potential BOD and produced no undesirable effect on the dissolved oxygen determination nor on reaeration. In working with systems containing domestic sewage, it became necessary to use another toxicant for this purpose. After much experimentation, a commercial preparation containing phenylmercuric acetate and a colloidal copper-silver alloy was found to be suitable for the purpose. The material is marketed under the trade name "Slimodyn."

Tap Water Studies

The studies conducted with tap water amounted in a certain sense to calibration of the equipment. To evaluate the effects of added sewage, it was first necessary to determine the reaeration rates in tap water under conditions including all those to be studied later in the presence of sewage.

Experimental Method

In preliminary studies, a number of experiments were performed in which the course of reaeration was followed by determining dissolved oxygen repeatedly in the same system after vari-

ous time intervals. In all such experiments it was found that the data fit the first-order reaeration formula in the form developed in an earlier phase of the study (4)

$$\log U_t = \log U_o - k_2 (\Delta t) \quad \ldots . (1)$$

within the analytical accuracy of the dissolved oxygen determinations. The same formulation, with varying values of k_2, was found to apply to quiescent systems and to systems stirred in various ways. These observations were in agreement both with the theoretical concept of the reaeration rate as a function of undersaturation, and with the observations of other authors (2) (3).

If the first-order formula is considered applicable, it is possible to calculate the value of the constant k_2 from only two analyses for dissolved oxygen, taken before and after a known interval of elapsed time. In practice, a single determination of k_2 by this technique is not altogether satisfactory, since the possibility of analytical errors in determining the undersaturation, about $\pm$ 0.1 mg/l, results in too much uncertainty about the true value of k_2. There are several possible methods for improving the precision of the observations:

1. A reaerating system may be analyzed for dissolved oxygen numerous times as reaeration proceeds, and k_2 may be calculated by the method of least squares.

2. The dissolved oxygen analyses may be replicated at the beginning and end of the experiment, in order to improve the precision of the undersaturation values used for calculation of k_2 from the two observed points.

3. The entire reaerating system may be replicated, and the k_2 values determined independently in each system, then averaged to give the most probable value of k_2 under the conditions represented by the experiment.

4. Various combinations of these techniques are possible. For example, replicate reaerating systems, replicate analyses, and analyses at several time intervals in each system might all be used, or any two of the methods might be combined.

For the purposes of this study, it was believed that there was some advantage to be gained by replicating the entire reaerating system. Although this method of replication involved handling much larger volumes of water and sewage than would have been required for any other technique, it had the advantage of providing for the cancellation of any slight differences of stirring, sample composition, or construction of the equipment which might otherwise tend to influence the results. On this basis, all the replication performed consisted in replicating the entire experiment. Rather than using replicate analyses, or analyses at various time intervals, several reaerating units were used, or repeat experiments were performed, to attain the precision of k_2 which was considered necessary.

To determine reaeration constants, the columns of the mixing apparatus, or unstirred columns of the same dimensions, were filled to a depth of 4 ft 2 in. The biological inhibitor (mercuric chloride or Slimodyn) was added in the quantity required to give the desired final concentration. The contents of the columns were then partially deaerated by passing compressed nitrogen through a carborundum diffuser dropped nearly to the bottom of each column. Stirring was started and dissolved oxygen was determined in the contents of each column. The time at which each sample was taken was noted. The temperature of the liquid and the barometric pressure at the time of sampling were recorded. The solubility of oxygen at the proper temperature was taken from the tables of Truesdale, Downing, and Lowden (5), and corrected for barometric pressure P by multiplying by the factor

$P/29.92$. The difference between the solubility and the observed dissolved oxygen concentration was recorded as U_o.

Reaeration was allowed to proceed for one to four days, depending on the rate of stirring. Each column was again sampled and analyzed for dissolved oxygen, and this figure was used with the liquid temperature and barometric pressure to calculate the undersaturation by the method just described.

The first-order reaeration constant k_2 was calculated for each column from Equation 1. Time was expressed in days, giving k_2 the units of reciprocal days.

The two temperature observations in a given column were averaged together. The resulting temperature was considered the mean temperature of the column during the experiment, and the value of k_2 was corrected to 20° by applying the formula

$$k_2 \text{ (at } 20°) = k_2 \text{ (observed)} \cdot \theta^{(20-T)} \quad \ldots (2)$$

where T represents the temperature. The value of θ, 1.047, was taken from Streeter *et al.* (6).

The replicate values of k_2 thus separately determined were then averaged arithmetically, and the resulting mean value of k_2 was taken as the most probable figure. The corresponding values of the constants f, r_o, and r_1 were readily calculated from k_2 whenever they were needed.

In all the studies of this series, the determinations of dissolved oxygen were performed by the polarographic method (7).

Results

The results of a number of determinations of the reaeration rate in tap water containing 20 mg/l of mercuric chloride, at various rates of circulation in the mixing apparatus, are presented graphically in Figure 3. The graph shows the data to be in a straight line.

From the individual determinations of k_2, the equation for the straight line of best fit was calculated by the method of least squares. In this calculation, each of the observed points was considered individually. The resulting equation was

$$k_2 = 0.0594 + 0.325M \quad \ldots (3)$$

where M represents the circulation rate in cycles per minute. The line plotted in Figure 3 is the graph of the equation.

After the propellers in the mixing apparatus were changed, it was concluded from the close agreement between the reaeration constants observed with the new propellers and those calculated from the circulation rate that recalculation of the equation was not necessary, since the same relationship between the rates of circulation and reaeration was evidently applicable. The reaeration constants determined

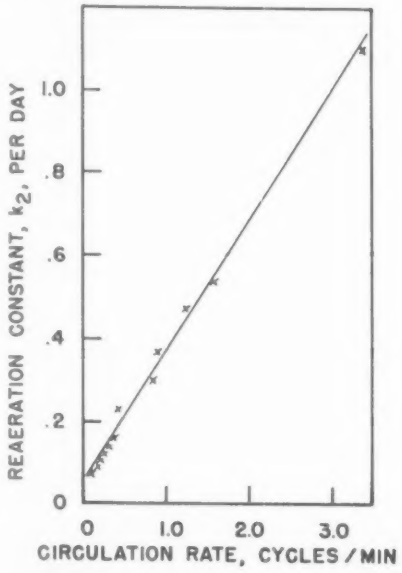

FIGURE 3.—Variation of reaeration constant with circulation rate in tap water containing mercuric chloride.

with the new propellers are included in Figure 3.

Solubility of Oxygen in Domestic Sewage

The solubility of atmospheric oxygen in domestic sewage was redetermined in connection with this work, for the purpose of indicating whether the absolute rate of reaeration in the presence of sewage results from reduced solubility of oxygen, or from a change in the rate of approach to the equilibrium dissolved oxygen concentration.

Experimental Method

Samples of sewage were brought to constant temperature and aerated with diffused air. Subsamples were taken and analyzed for dissolved oxygen repeatedly during the aeration, at intervals of about 30 min, until no further increase of dissolved oxygen concentration was observed. The aeration was continued about 2 hr longer, and the analysis was repeated, to demonstrate that equilibrium had truly been attained.

Before each experiment, the sewage to be used was heat-treated by boiling for about 15 min. There was no attempt to keep the sewage sterile during the experiment. The purpose of this procedure was to reduce the microbial population of the sewage to such a point that biological utilization of oxygen would not occur at a rate sufficiently high to affect the equilibrium significantly. Although absolute sterility was not considered necessary for this purpose, reduction of the relatively high microbial population of sewage did seem to be a desirable precaution.

The polarographic method was employed for the dissolved oxygen determinations. Before each analysis, the instrument was calibrated on a sample of 0.01 M KCl, saturated with air at the same temperature as the sewage to be analyzed. The concentration of dissolved oxygen in these standards was calculated from the published figures for the solubility of oxygen in distilled water and in sea water (5) (8). The equivalent salinity of 0.01 M KCl is 584 mg/l and it was assumed that the solubility of oxygen in this solution was the same as in a sea water dilution of the same salinity. Since the salinity correction is small, extreme accuracy in its estimation was not required.

TABLE I.—Solubility of Atmospheric Oxygen in Domestic Sewage

Temperature (° C)	Sewage (per cent)	Solubility, Per Cent of Distilled Water Value	
		Average	Range
10	100	98.0	95.0–102.8
10	25	100.3	98.0–100.8
10	10	98.3	98.1–98.8
20	100	99.7	94.8–103.7
20	25	101.2	98.4–105.4
20	10	97.7	95.5–100.7
27	100	99.7	99.5–99.9
30	100	101.3	96.0–104.9
30	25	98.4	96.6–100.6
30	10	98.2	96.0–102.5

Eight different sewage samples were used. With each sewage two separate experiments were performed at 10°C, two at 20°C, and two at 30°C. Three of the sewages were diluted to 10 and 25 per cent with tap water, and each dilution was similarly tested twice at each temperature.

In addition, in several of the reaeration experiments, after the reaeration rates had been determined, compressed air was bubbled through the sewage from a carborundum diffuser, and the concentration of dissolved oxygen was determined repeatedly until no further increase occurred over a 30-min period.

Results

The results of the various determinations are compiled in Table I. It may be seen that none of the average values differs from the corresponding value for pure water by more than

2 per cent. Only in two instances are the extremes of the ranges more than 5 per cent from the distilled water value. It was concluded, therefore, that the solubility of oxygen in sewage is not significantly different from its solubility in pure water. When the work of Moore (9) is compared to the most recently published figures for the solubility of oxygen in pure water, the same conclusion results. This indicates that any effect on reaeration resulting from the presence of domestic sewage represents a change in the rate at which the system approaches equilibrium, and not a change in the solubility of oxygen.

Effect of Sewage Strength and Concentration on Reaeration Rate

A fixed rate of stirring and a single source of sewage samples were employed in this phase of the work, in order to minimize the number of variables. It was desired at this stage to investigate only the question of whether a regular relationship could be observed between the reaeration rate and the degree of pollution.

The extent to which water is polluted may be expressed on the basis of several different analytical criteria. A second purpose of this part of the studies was to test the relative value of some of these indexes of pollution as indicators of the effect of the pollution on reaeration.

Experimental Method

As each sample of sewage was being collected, it was passed through a 60-mesh wire screen, to remove coarse settleable particles. The cylinders of the mixing apparatus were filled to a depth of 4 ft, 2 in., which required a volume of approximately 20.9 l per cylinder. When quiescent studies were conducted with the same sewage sample, unstirred cylinders of the same dimensions as those in the mixing apparatus were filled to the same depth. When sewage dilutions were employed, the predetermined volume of sewage was placed in each cylinder, and the cylinders were then filled with tap water. A portion of the sewage was reserved, or an extra portion of the sewage dilution was prepared, for use in the analyses. Ten milliliters of Slimodyn were added to each cylinder, to give a Slimodyn concentration of approximately 480 mg/l. The contents of the cylinders were deaerated by bubbling compressed nitrogen through them from carborundum diffusers. Stirring was started, and the propeller speed was adjusted to 90 rpm, giving a circulation rate of 0.480 cycles per minute. A 10-ml sample was removed from each column with a pipette and immediately analyzed for dissolved oxygen. The dissolved oxygen analysis was repeated approximately two days later on the contents of the stirred cylinders, and after approximately four days' reaeration on the quiescent systems. In most of the work involving reaeration of sewage and sewage dilutions, the temperature was maintained at 20°C. In the experiments performed at room temperature, both the dissolved oxygen analyses and the observed reaeration rates were corrected to 20°C by methods of calculation previously discussed. The dissolved oxygen analyses, barometer readings, and, where applicable, the temperature readings, were used to calculate the value of k_2 for each cylinder, according to the method illustrated in connection with the reaeration of tap water. After the reaeration constant had been so determined once in each cylinder, the entire group of cylinders was again deaerated and the reaeration rate was observed again, giving a total of 12 replicates for each set of conditions.

Results

Each set of 12 replicate reaeration constants was combined and its mean value was calculated. The resulting mean values, together with the analyti-

TABLE II.—Reaeration Constants Observed at Various Levels of Pollution

Expt. No.	Sewage (per cent)	BOD (mg/l)	Turbidity (mg/l)	Grease (mg/l)	Surface Tension (dynes/cm @ 25°C)	NH_3-N (mg/l)	Total N (mg/l)	Suspended Solids		Total Solids		k_2	
								Total (mg/l)	Volatile (mg/l)	Total (mg/l)	Volatile (mg/l)	Per Day	Per Cent Tap Water
(a) Circulation Rate: 0.48 Cycles/min													
77	10	17	27	10.0	69.8	1.5	27.0	19.7	15.0	68.8	37.2	0.212	98.5
81	13	23	23	8.4	66.1	7.0	8.9	11.4	10.7	68.5	33.7	0.201	93.5
79	30	31	25	10.1	—	0.3	6.8	3.3	3.3	99.0	78.0	0.200	93.0
76	25	40	35	17.0	70.1	3.2	6.5	21.0	17.8	122.0	58.0	0.197	91.5
67	100	70	48	14.0	70.5	5.0	7.5	—	—	—	—	0.162	75.3
69	100	120	107	18.9	70.8	10.0	30.0	26.8	17.6	494.0	326.0	0.139	64.6
68	100	202	103	34.8	58.8	17.6	30.1	29.0	27.0	424.0	184.0	0.123	57.2
(b) Quiescent													
77	10	17	27	10.0	69.8	1.5	27.0	19.7	15.0	68.8	37.2	0.0589	99.1
81	13	23	23	8.4	66.1	7.0	8.9	11.4	10.7	68.5	33.7	0.0552	92.9
79	30	31	25	10.1	—	0.3	6.8	3.3	3.3	99.0	78.0	0.0543	91.4
76	25	40	35	17.0	70.1	3.2	6.5	21.0	17.8	122.0	58.0	0.0530	89.2
67	100	70	48	14.0	70.5	5.0	7.5	—	—	—	—	0.0462	77.8
78	100	103	84	33.6	70.8	1.0	22.6	11.0	11.0	330.0	256.0	0.0417	69.0
86	100	115	185	39.8	68.0	11.3	23.1	—	—	—	—	0.0407	68.5
69	100	120	107	18.9	70.8	10.0	30.0	26.8	17.6	494.0	326.0	0.0401	67.5
81	100	180	180	65.5	61.3	14.4	18.2	112.0	96.0	536.0	264.0	0.0351	59.1

cal results on the corresponding sewage samples and sewage dilutions, are compiled in Table II. The results are arranged in order of decreasing reaeration rate, and the experiment numbers are included for convenience in referring to the particular experiments in the discussion.

Effect of Mixing Rate

In Table II it may also be seen that sewage of a given strength had about the same relative effect on the reaeration rate in stirred and unstirred systems. In other words, the observed reaeration constant was found to be approximately the same percentage of the corresponding tap water rate, for a given level of pollution, whether the system was stirred or quiescent. This observation excited some curiosity as to how far this same relationship might extend—whether it was characteristic only of the slow movement beneath a smooth, unbroken surface that occurred with the circulation rate of 0.48 cycles per minute, or whether the same effect might result from a given level of pollution under conditions of more vigorous agitation.

Subsurface Propeller Blades

The first tests designed to answer this question were performed with the maximum propeller speed possible with the mixing apparatus constructed as it was at the time. The propellers were driven at 210 rpm, resulting in a circulation rate of 1.12 cycles per minute. At this rate much rippling and rotation of the water surface were apparent. The tap water value of the first-order reaeration constant calculated from the circulation rate was 0.432.

The results of three such experiments are presented in Table III, along with the results of analysis of the samples employed.

For comparison of these results with those observed in the systems in which the water surface was undisturbed, two of the samples tested at the high stirring rate were also tested with no stirring. The results of these experiments are included in Table II as Experiments 78 and 86. In a quiescent system, the sewage having a BOD of 103 mg/l gave a reaeration rate 69.0 per cent of the corresponding tap water value; at a circulation rate of 1.12

TABLE III.—Results of Reaeration Experiments with Circulation at 1.12 Cycles/Min

Sewage (per cent)	BOD (mg/l)	Turbidity (mg/l)	Grease (mg/l)	Surface Tension (dynes/cm @ 25°C)	NH_3-N (mg/l)	Total N (mg/l)	Suspended Solids		Total Solids		k_2	
							Total (mg/l)	Volatile (mg/l)	Total (mg/l)	Volatile (mg/l)	Per Day	Per Cent Tap Water
50	52	42	16.8	—	0.5	11.3	5.5	5.5	165	128	0.364	84.2
100	103	84	33.6	70.8	1.0	22.6	11.0	11.0	330	256	0.296	68.5
100	115	185	39.8	68.0	11.3	23.1	—	—	—	—	0.291	67.3

cycles per minute, the reaeration rate was 68.5 per cent of the tap water rate. With the sewage having a BOD of 112 mg/l, the quiescent reaeration rate was 68.5 per cent of the quiescent tap water rate, and in the stirred system, the rate was 67.3 per cent of the rate calculated for tap water. Although in both cases the percentage of the tap water rate is less in the stirred system, the differences from the results in the quiescent systems are insignificantly small, and it may be said that the sewage produced the same relative effect, stirred or unstirred, in each case.

The result obtained in the 50-per cent sewage dilution reported in Table III may be evaluated as follows. From the data of Table II, a graph was constructed, relating reaeration rate, as percentage of the tap water rate, to the BOD (Figure 4). Although other analytical values could be substituted, the BOD was used because it appeared from the data of Table II that it was likely to give the best estimate of the reaeration rate.

From Figure 4 it would be estimated that a BOD of 52 mg/l should give a reaeration rate a fraction over 85 per cent of the tap water rate. For a circulation rate of 1.12 cycles per minute, the calculated value of the first-order reaeration constant is 0.432. Therefore, the predicted value of k_2 in the system containing 52 mg/l of BOD is approximately 0.37. The mean of 12 replicate observed values was 0.364.

TABLE IV.—Comparison of Observed Reaeration Rates with Those Calculated From Figure 4

BOD (mg/l)	Estimated		Observed	
	Per Cent Tap Water	k_2 (per day)	Per Cent Tap Water	k_2 (per day)
52	85.2	0.368	84.2	0.364
103	70.8	0.306	68.5	0.296
115	67.5	0.292	67.3	0.291

A comparison of the reaeration rates observed at the higher stirring rate with those estimated from Figure 4 appears in Table IV.

From the foregoing, it was concluded that the relationship between the level of pollution and the relative effect on the reaeration rate might be considered constant up to the maximum rate of stirring tested.

Additional Surface Blades

The propeller shafts of the mixing apparatus were then fitted with additional blades, so placed that they cut through the water surface and produced relatively violent surface agitation when the mixer was in operation. A single experiment was performed, using this modification and a propeller speed of 180 rpm. Since it was necessary to determine the tap water rate in this system, because calculation of the tap water rate was impossible, three of the cylinders were filled with tap water and three with sewage, and the reaeration rates were determined four separate times in each column. The average tap water value of k_2 was found to be 2.14 per day. The sewage BOD was 140 mg/l. The exact posi-

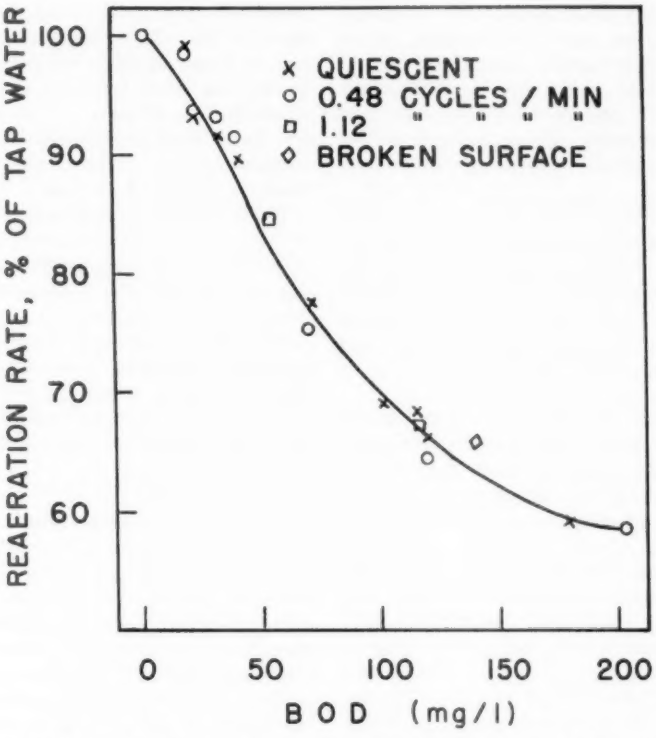

FIGURE 4.—Relationship of reaeration rate as percentage of tap water rate to BOD.

tion of the best line in Figure 4 is somewhat uncertain in that range of BOD values, but it was estimated that the value of k_2 should be roughly 64 per cent of the tap water value. The observed mean value of k_2 in the columns containing sewage was 1.44 per day, which is 67.2 per cent of the tap water value observed in the same system. The calculated value of k_2 in sewage, 64 per cent of 2.14, would be 1.37 per day.

Similar Results

It was concluded from these observations that the effect on reaeration resulting from a given level of pollution is independent of the turbulence of the system over the range tested. How much farther in the direction of greater turbulence this same situation may extend, whether it applies to aeration by spraying or by diffused air, is not indicated by these data, and would have to be determined in separate experiments.

Discussion

Reaeration and Circulation

In the studies with unpolluted water, it was observed that the rate of reaeration bore a linear relationship to the rate of circulation over the entire range of stirring rates tested. This was not particularly unexpected, since reaeration rates are theoretically related to the rate at which new, unsaturated water surfaces are exposed to the atmosphere. Nevertheless, it is of in-

terest that when the water is circulated beneath an unbroken surface, as in these experiments, the effect on the reaeration rate is uncomplicated. O'Connor and Dobbins (10) show that the reaeration rate is related to the rate of surface renewal by the equation

$$k_2 = (Dr)^{1/2}/2.31\ L \quad \ldots\ldots (4)$$

where D = the diffusion constant of dissolved oxygen within the surface film of the water;
r = the fraction of the surface renewed per unit time; and
L = the liquid depth.

Therefore, the fact that k_2 was found to be a linear function of the circulation rate indicates that the rate of surface renewal varied as the square of the circulation rate in the study system.

Over an even wider range of stirring rates, a given concentration of domestic sewage produced reaeration rates which bore a constant relationship to the corresponding rates of reaeration of unpolluted water.

From these two observations, it follows that with a fixed level of pollution, the relationship between the rates of circulation and of reaeration must likewise be linear.

Diffusion Constant

The solubility of atmospheric oxygen in sewage was found to differ insignificantly from its solubility in distilled water. The decreased rates of reaeration observed in the presence of sewage cannot, therefore, be interpreted as indicating any change in the equilibrium, or saturation, concentration of dissolved oxygen. Since the solubility of oxygen is not changed by the presence of sewage, the undersaturation for a given concentration of dissolved oxygen is the same with or without sewage present. The slower reaeration in the presence of sewage means, therefore, that the undersaturation is satisfied at a lower relative rate. This is correctly expressed as a lower value of k_2. Referring back to Equation 4, it appears that the factor which is changed by the presence of pollution must be the diffusion constant, since the depth, and presumably the rate of surface renewal, remain constant for fixed conditions of stirring.

From Table II, it is apparent that the lower reaeration constants are characteristically associated with the higher degrees of pollution. Reading downward in any column of analytical values shows a general trend in the direction indicating heavier pollution. This, of course, would be expected if it is assumed that pollution has any effect on reaeration whatever.

BOD and Reacration Rates

Only the BOD results, however, show a consistent and regular change when arranged according to the corresponding reaeration results. In each of the other columns of analytical values, although the trend toward greater effect on reaeration with heavier pollution generally applies, it is possible to pick out pairs of experiments in which the results of a particular analysis seem to be reversed.

In the inception of this phase of the work, it was anticipated that mathematical analysis of the correlation between the reaeration rate and each of the analytically determined values would be employed, to show which analyses might serve best to indicate the effect on reaeration to be expected from a given level of pollution. After examination of the data of Table II, however, it was considered obvious without further mathematical demonstration that none of the other analyses would correlate with the observed reaeration rates as well as the BOD.

This result was unexpected. A change in the rate of equilibration across an interface can hardly be visualized as anything but a surface effect. Consequently, it was anticipated a priori that the best index of

the reaeration rate might be found either in a direct observation of the surface properties, such as the surface tension, or among the analyses related to materials of recognized surface activity. Careful consideration of the analyses employed reveals a number of points which collectively may explain the observed results.

Surface Tension

In the case of the surface tension, the range of variation is small relative to the precision of the determination. The lowest value encountered in these studies was 58.8 dynes/cm, 13.0 dynes/cm less than the accepted value for distilled water. Most of the values were found to be between 66 and 71 dynes/cm. Since experience reveals surface tension determinations usually to be subject to errors of five per cent or over, the variations within such a narrow range can hardly be regarded as even significant. In only a few cases is it certain that the observed values differ from the value for distilled water by more than the analytical error.

Grease

The grease determinations generally correlate fairly well with the reaeration results. It might be expected at the first thought that the correlation would be very strong, since a film of grease completely or even partially covering the air-water interface could readily be visualized as having a rather profound effect on reaeration. Certain flaws appear in this reasoning, however, especially on close examination of the details of the method of grease determination. First, in the standard method (11) by which these analyses were performed, the sewage sample is strongly acidified before the grease is separated from it. This technique tends to convert all soaps present, whether soluble or precipitated as insoluble salts, to free fatty acids which are then included in the grease determined. At the same time, any basic surface-active materials, insoluble in water at the pH of the sewage, tend to be made soluble in the presence of acid and will then fail to be removed and determined as grease. The two effects may not, and in most cases probably will not, exactly counterbalance.

The grease determination, requiring separation of a small quantity of the material to be determined from a relatively large volume of sample, is naturally inclined to be rather susceptible to errors arising from losses or contamination of the sample. The procedure involves quantitative transfer of a sizable quantity of filter aid, containing the greases, from a vacuum filter to an extraction thimble. It is at this step that loss or contamination is probably most apt to occur. The greases are finally weighed in a 200-ml flask. The weight of the flask is large compared to the weight of the grease, and its large surface area may favor adherence of a significant weight of moisture or dust. For these reasons, the accuracy of the determination of the grease content of the samples may leave something to be desired.

Finally, it may not be exactly true that the grease content of the sewage is an accurate indication of the tendency for a film of grease to form at the air-water interface. A large part of the grease may tend rather to collect at liquid-solid interfaces, particularly where these intersect the air-water surface. All of these considerations combined may explain why no better correlation was observed between the results of the grease determinations and the effect of the various samples on reaeration.

Proteins

Another chemical class of sewage constituents having surface activity is the proteins. Their concentration is related to the concentration of organic nitrogen shown in the tables of analytical results.

There are several reasons, however,

why the organic nitrogen analyses cannot accurately reflect the effect of the proteins on reaeration.

1. It would be expected that the more hydrophilic proteins would have a greater effect than a comparable concentration of insoluble proteins, but the analytical method makes no distinction between the two classes.
2. Even among various hydrophilic proteins, a difference in the extent of the surface effect per unit amount of nitrogen might be expected.

Fresh domestic sewage always contains urea, which decomposes within a few hours to ammonium carbonate. If a sample is taken from a sewer system which has a fairly short transit time, and the analyses are performed promptly, the urea nitrogen appears as a part of the organic nitrogen. But if a longer time elapses, then the nitrogen originally present as urea appears as ammonia. Since the urea-nitrogen of fresh sewage sometimes constitutes as much as 50 per cent of the total nitrogen present, these variations in its partition between organic nitrogen and ammonia have much influence on the apparent relationship between organic nitrogen concentration and reaeration.

Contamination Possibilities

It would be highly desirable to present a truly general relationship between some analytical criterion of the degree of pollution and the corresponding effect on reaeration rates, a relationship which would apply to many other types of pollution as well as that due to the presence of domestic sewage. Probably such a relationship could not be based on any of the types of analyses which were performed in the present work. More likely it would have to be a function of the concentration of grease plus the concentration of soluble proteinaceous material, and it might not be simple in form. Perhaps, for strictest accuracy and widest application, certain polysaccharides would also have to be considered, since some of them, such as gums and pectins, are colloidal in nature and may be expected to show some degree of surface activity. Certainly the grease determinations would have to relate more exactly to the materials which behave as greases in the reaeration experiments than do the determinations reported here. Likewise, the standard organic nitrogen analyses would probably have to be abandoned in favor of a test which provides a more direct indication of the concentration of soluble proteins present, without interference from insoluble proteins, from urea, or from any of the other compounds which contribute to the total organic nitrogen found in sewage.

Significance of BOD

In the absence of such a generally applicable parameter, the standard BOD test appears to give a fairly good indication of the effect on reaeration to be expected, when the predictions are confined to domestic sewage alone. The BOD of the individual constituents of sewage can hardly be considered to be directly related to their effects on reaeration. It is far more probable that because the concentrations of the various constituents of domestic sewage tend to vary together, any fairly accurate parameter of the over-all strength of the sewage also provides a good relative indication of the concentrations of those constituents which affect reaeration. In other words, the concentration of those compounds in domestic sewage which affect the reaeration rate appears to be approximately proportional to the BOD, but the BOD and the effect on reaeration are not necessarily caused by the same materials.

There appears to be no obvious theoretical reason why the BOD determination should be an especially good indicator of the effect of sewage on reaeration rates. Although it hardly

seems probable, the possibility must even be admitted that the observed regularity of the relationship is merely fortuitous. On the other hand, it is more likely that the value of the BOD determination lies in the fact that it provides a rather accurate and sensitive index of the degree of pollution, and varies over a range which is wide in comparison to the errors involved in its determination. So long as the pollution consists of domestic sewage, as it did in these studies, the BOD is a relatively good indicator of the pollutional level present, which in turn determines the effect on reaeration.

In the graph of Figure 4, in which the observed reaeration rate is plotted against the BOD, the slope tends to decrease at high levels of pollution, indicating that successive increments of pollutional concentration have a decreasing effect on the reaeration rate. Thus, it appears that as the air-water interface contains increasing concentrations of the substances affecting reaeration, it becomes less responsive to further increases in the concentration of such substances in the solution beneath it. Either it is more difficult, on the basis of the energy required, for more of the surface-active materials to enter the surface, or successive increases of their concentration in the surface have decreasing effects on the reaeration. This sort of relationship is characteristic of many surface phenomena, and it is not surprising, therefore, that it should be observed in this case.

Fraction of Sewage in Sample

The volumetric percentage of sewage in the sample was used as the only parameter of the degree of pollution in the report of the studies of Kehr (1) of the effect of sewage on reaeration. The results reported in Table II show that this is not a satisfactory parameter. The results of Experiments 76 and 79, in particular, show that the pollutional characteristics of the mixture are of more significance, whether the mixture contains a small percentage of strong sewage, or a higher percentage of weak sewage. The several experiments with undiluted sewage show a wide range of effects on reaeration, depending on the sewage strength.

Of particular interest in this connection are the results obtained in the range of sewage concentration from 25 per cent downward. Kehr reported very marked effects on reaeration by this range of sewage concentrations, such that 25-per cent sewage reduced the reaeration rate to 44 per cent of the tap water value, and even 1 per cent sewage resulted in a reaeration rate only 74 per cent of that in tap water. In the experiments described herein, the reaeration rate was found to be at least 90 per cent of the tap water value in the presence of sewage concentrations up to 30 per cent. The reaeration constants observed in Experiments 77 and 81 (10- and 13-per cent sewage, respectively) do not differ from the tap water values by more than the error of their determination.

Kehr reported no reaeration results for mixtures containing more than 25 per cent sewage, because he found it impossible to prevent biological utilization of oxygen in higher concentrations. Possibly the low reaeration rates he reported in higher dilutions of sewage are due to the fact that some biological action also occurred in those experiments, although it was apparently not recognized. It was found in the present experiments that complete elimination of biological respiration requires fairly drastic conditions, and even limited utilization of oxygen greatly decreases the apparent reaeration rate.

The effect of these relatively low levels of pollution is of particular interest in connection with stream sanitation studies. In polluted natural waters, the concentration of pollution most frequently lies in this range. Although

it occasionally happens that sewage constitutes more than 10 per cent of the volume of a stream or lake, such situations are relatively rare. Thus, the finding that moderate pollution does not depress the reaeration rate far below that occurring in unpolluted water is of special importance.

Further Comparisons with Others

In undiluted domestic sewage of average strength (BOD of 150 to 200 mg/l), reaeration rates were found to be approximately 60 per cent of the rate observed in tap water under the same conditions. The actual reaeration data at these high pollutional loadings are of less significance in stream sanitation than in sewage treatment processes involving aeration. Frequently, relative reaeration rates in undiluted sewage have been reported to be lower than the figures presented here. One of the more recent reports, for example, is that of King (12), who gives reaeration rates for undiluted sewage ranging from 15 to 30 per cent of the tap water rate. In his studies, as in most others, no attempt to sterilize the sewage or otherwise control biological action is reported. It must be assumed, therefore, that the low reaeration rates observed actually represent the difference between the rate of reaeration and the rate of microbial respiration.

A series of recent British papers (2) (3) presents results which indicate that the effect of domestic sewage on reaeration is approximately as great as that reported earlier (1). These experiments appear to be much more satisfactory, from a technical standpoint, than the older studies, and there is no immediate obvious explanation for the difference between the results of the separate studies. It may be pertinent to point out, however, that in general the British studies deal with higher reaeration rates than those reported here. Possibly, then, the relative effect of pollution may change as the absolute reaeration rate increases over a wide range.

Summary

This investigation constitutes a reexamination of the effect of domestic sewage on atmospheric reaeration of water.

The solubility of oxygen in sewage does not differ significantly from its solubility in pure water under the same conditions, which corroborates the results of previously published work.

Addition of some of the commonly used chemical inhibitors of respiration did not result in reducing the biological utilization of dissolved oxygen to a level sufficiently low to permit accurate determination of the reaeration rate. However, conditions were eventually developed which made possible the observation of reaeration rates, without errors caused by microbial oxygen utilization during the experiments.

Domestic sewage was found to cause a decrease of the reaeration rate, and as the degree of pollution becomes heavier, the reaeration rate is affected to a greater extent. However, the effect of a given level of pollution was found to be substantially less than has been stated elsewhere. Even when sewage comprises as much as 10 per cent (by volume) of the mixture, the reaeration rate differed from that occurring in tap water by only about 5 per cent.

Undiluted sewage of average strength was found to reaerate at about 60 per cent of the corresponding tap water rate.

Various analytical indexes of the degree of pollution were compared with the observed reaeration rates to determine whether any one of them was particularly valid as an indicator of the effect on reaeration to be expected from a given degree of pollution. Since all the analytical criteria vary together when the pollutional concentration is changed, the best indications are obtained from those analyses which can be most accurately determined, which

vary over the widest ranges, and which are least subject to distortion of the analytical results by substances other than those they are intended to determine. Of the various analyses examined, the biological oxygen demand correlated best with the reaeration rate, even though it must bear an indirect, rather than a direct, relationship to the substances present which affect reaeration.

The experiments were conducted both in quiescent and in gently stirred systems. In a few experiments, the reaeration liquid was more vigorously agitated. In one case the surface was deliberately broken by special stirring vanes. Over the entire tested range of stirring rates, and consequent reaeration rates, sewage was found to have the same relative effect on reaeration as in quiescent water.

The rate of reaeration of clean water was directly proportional to the rate of circulation of the water, under conditions ranging from quiescence through various rates of gentle stirring such that the surface remained unbroken. Since the reaeration rate at a given level of pollution is a fixed percentage of the corresponding tap water rate, regardless of the rate of stirring, it analytical indexes of the degree of polluted water is also a linear function of the circulation rate.

Conclusions

From consideration of the results of these studies, the following conclusions are drawn:

1. The rate of atmospheric reaeration is directly proportional to the rate of circulation of the water, within the limits of turbulence where the water surface remains unbroken.

2. The solubility of oxygen in sewage is not significantly different from its solubility in pure water.

3. Domestic sewage depresses the reaeration rate of water, the extent of the depression depending on the strength of the sewage and the relative quantity of it present.

4. With various degrees of turbulence, ranging from quiescent conditions to fairly violent agitation and a broken water surface, the relative effect of a given concentration of domestic sewage on reaeration remained unchanged under our conditions.

5. The reaeration rate of undiluted domestic sewage of average strength is about 60 per cent as great as that of clean water under the same conditions.

6. Polluted streams are unlikely to contain enough sewage to depress reaeration to less than 95 per cent of the clean water rate.

7. In domestic sewage, the concentration of the compounds affecting reaeration is proportional to the BOD of the sewage and the BOD gives a better indication of the effect on reaeration than do other standard analytical indexes of the degree of pollution even though the relationship must be an indirect one.

Acknowledgment

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References

1. Kehr, R. W., "Measures of Natural Oxidation in Polluted Streams. IV. Effect of Sewage on Atmospheric Reaeration Rates under Stream Flow Conditions." *Sewage Works Jour.*, **10**, 2, 228 (Mar. 1938).
2. Gameson, A. L. H., Truesdale, G. A., and Varley, R. A., "Some Factors Affecting the Aeration of Flowing Water." *Water and San. Engr.* (Brit.), **6**, 2, 52 (July/Aug. 1956).
3. Downing, A. L., Melbourne, K. V., and Bruce, A. M., "The Effect of Contaminants on the Rate of Aeration of Water." *Jour. Appl. Chem.* (Brit.), **7**, 590 (1957).
4. Rand, M. C., "Concepts of Surface Reaeration—A Critical Review." THIS JOURNAL, **29**, 11, 1282 (Nov. 1957).
5. Truesdale, G. A., Downing, A. L., and

Lowden, G. F., "The Solubility of Oxygen in Pure Water and Sea Water." *Jour. Appl. Chem.* (Brit.), **5**, 53 (1955).

6. Streeter, H. W., Wright, C. T., and Kehr, R. W., "Measures of Natural Oxidation in Polluted Streams. III. An Experimental Study of Atmospheric Reaeration under Stream-Flow Conditions." *Sewage Works Jour.*, **8**, 2, 282 (Mar. 1936).
7. Rand, M. C., and Heukelekian, H., "Determination of Dissolved Oxygen in Industrial Wastes by the Winkler and Polarographic Methods." THIS JOURNAL, **23**, 9, 1141 (Sept. 1951).
8. Gameson, A. L. H., and Robertson, K. G., "The Solubility of Oxygen in Pure Water and Sea Water." *Jour. Appl. Chem.* (Brit.), **5**, 502 (1955).
9. Moore, W. A., "The Solubility of Atmospheric Oxygen in Sewage." *Sewage Works Jour.*, **10**, 2, 241 (Mar. 1938).
10. O'Connor, D. J., and Dobbins, W. E., "The Mechanics of Reaeration in Natural Streams." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **82**, SA 6, 1115 (1956).
11. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
12. King, H. R., "Mechanics of Oxygen Absorption in Spiral Flow Aeration Tanks. II. Experimental Work." THIS JOURNAL, **27**, 9, 1007 (Sept. 1955).

DIRECTORY OF MEMBERS

For the first time, in March 1960, the Journal will appear as two separate issues. The special issue will contain the complete membership listing for the calendar year of 1959.

If your latest listing (March 1958 or March 1959) was incorrect or incomplete you are urged to send your latest information to the Federation office NOW! The membership listing can be only as accurate as the information received from you. If nothing is received, the listing will be based on the most recent information.

The personal data needed are:

1. Name and title.
2. Correct mailing address for Journal.
3. Employer or name of your firm.
4. Member Association.

Be certain that your Member Association receives the same information.

This information MUST be received in the Federation Office by December 31, 1959.

THE OPERATOR'S CORNER

WHAT CAN THE OPERATOR DO TO PROMOTE BETTER PUBLIC RELATIONS?*

By George C. Ahrens

Howard R. Green Co., Cedar Rapids, Iowa

Public relations is reported to be the fastest-growing profession in America today. What is public relations? It is the execution of a program of action to earn public understanding. It might better be called public information.

Utilities in the past have had poor histories in the matter of public relations. Someone at the top has failed to recognize the fact that a utility is a public servant. It should be remembered that the individuals to whom service is rendered are the same ones who will be asked, at times, to pass on bond issues and elect city officials who will act on rate and salary increases; they are the same ones with whom the superintendent must work.

Human Relations

For good public relations, good human relations—with employees, with public officials or management, and with the public, the customers—are needed.

To foster good employee relations give the employee a title that denotes a certain amount of ability. Provide an employees' manual covering employment, vacation, holidays, sick leave, overtime, wages, etc. Each employee is the "utility" or "company" to the customers and also to his circle of friends and relatives. If he takes satisfaction in his job and pride in the utility, his attitude in itself will promote good public relations.

How to Get Along with People

Fundamental Techniques in Handling People

1. Don't criticize, condemn, or complain.
2. Give honest, sincere appreciation.
3. Arouse in the other person an eager want.

Six Ways to Make People Like You

1. Become genuinely interested in other people.
2. Smile.
3. Remember that a man's name is to him the sweetest and most important sound in the English language.
4. Be a good listener. Encourage others to talk about themselves.
5. Talk in terms of the other man's interest.
6. Make the other person feel important—and do it sincerely.

Twelve Ways to Win People to Your Way of Thinking

1. The only way to get the best of an argument is to avoid it.
2. Show respect for the other man's opinion.
3. If you are wrong, admit it quickly and emphatically.
4. Begin in a friendly way.
5. Get the other person saying "Yes, yes" immediately.

* Presented at the 41st Annual Meeting, Iowa Sewage and Industrial Wastes Assn.; Cedar Rapids, Iowa; June 17–19, 1959.

6. Let the other man do a great deal of the talking.
7. Let the other man feel that the idea is his.
8. Try honestly to see things from the other person's point of view.
9. Be sympathetic with the other person's ideas and desires.
10. Appeal to the nobler motives.
11. Dramatize your ideas.
12. Throw down a challenge.

Nine Ways to Change People without Offending

1. Begin with praise and honest appreciation.
2. Call attention to mistakes indirectly.
3. Talk about your own mistakes before criticizing the other person.
4. Ask questions instead of giving direct orders.
5. Let the other man save his face.
6. Praise the slightest improvement and praise every improvement. Be hearty in your approbation and lavish in your praise.
7. Give the other person a fine reputation to live up to.
8. Encourage. Make the fault seem easy to correct.
9. Make the other person happy about doing the thing you suggest.

Relations with City Officials

Obtain the support and good will of your city officials. This lays the groundwork for good public relations. It is most important that the officials understand how your department functions, what its needs and problems are, and how it is planning for the future. Keep your officials informed. Nothing annoys an elected official more than to learn first about your problems by reading it in the newspaper.

Relations with the Public

The secret of good public relations is to take the public into full confidence by making correct and honest statements. You must merchandise what you are doing.

What are the tools available?—they are: the press, radio, TV, public meetings, talks before civic and other organizations, such things as regular guided tours, visits by school classes, a large flow diagram on the plant wall, booklet describing the plant and system, street signs to tell what is being done on a project, exhibits and posters in office lobby or city hall, good housekeeping, attractive signs naming all equipment, a float in the annual parade, display at flower and garden show, sound motion pictures, good telephone contacts, and a smile and a genuine "thank you" at the paying window. Much information is contained in *Willing Water* which is published by the American Water Works Association.

Friendliness begets friendliness. One satisfied customer can do more to improve public relations than a dozen ads. Teach the necessity of courtesy—it is the cheapest commodity in the world. Good will is the most priceless asset a business or utility can possess.

W. S. Foster, Editor of *The American City*, offers the following suggestions:

1. He would eliminate the words "sewer" and "sewage" from any departmental title. He would also have a single department of water with divisions of supply and disposal.

2. Take down "No-admittance" signs and replace them with "Welcome" signs. Post the visiting hours below "Welcome."

3. Encourage trips through the plant by service clubs, school children, and others.

4. Allow the use of suitable grounds for recreation and picnic areas.

5. Enclose with the monthly bill an extra folder telling something about the plant or system. A leaflet about future extensions or the care of lawns, shrubberies, and trees will be appreciated too.

6. On complaints, Mr. Foster would work out a detailed system of handling, including names and addresses, nature of complaint, name of person who received the complaint, to whom it was referred, and action taken. Followup would be with a letter of thanks describing the action taken.

How to Build Good Press Relations

1. Newspapers exist to inform the public, the same public you serve.

2. Do not confuse public relations with publicity. Just getting space in the local paper is not enough. It must be filled with planned, factual information.

3. Keep the newspaper informed on what is happening. The time to get acquainted is when things are going well.

4. Know the city editor. He will tell you how news is handled and probably assign a reporter to cover your department. The reporter will be eager to work with you in developing news from your department. Don't go over his head, always tell him first. Don't hold back, give him all the facts whether they are favorable or not.

5. What is news? News items are: unusual operating conditions, emergencies, new facilities, rate changes, long-range plans, expansions, annual reports, bond issues, regulations, participation in meetings, unusual jobs, employee activities, and human interest stories.

6. Newpapers have deadlines; keep them in mind. Get information a reporter needs if you do not have it at hand. Don't complain about an unimportant error.

7. Stories in news columns are more likely to be read than ads. When advertising, use display type. People won't wade through 250 words to gain a thought or point. Humanize the advertising. Dramatize financial statements.

8. Whether your relations with the press are good, bad, or indifferent depends largely on you.

It must be remembered that ads, displays, and booklets cannot repair completely the injury done by a thoughtless employee.

Some Hints on Giving a Talk

1. State your facts; argue for them and appeal for action.

2. When you show that something is wrong, show how to remedy it; appeal for action.

3. Secure interested attention, win confidence, state your facts, appeal to the motives which make people act.

4. A speech must have punch. Appeal with real conviction and enthusiasm.

5. The speaker must have something which he really wants to say. Think over your facts, burn their real importance into your mind. Act enthusiastically and your audience will be enthusiastic.

6. A good talk is conversation enlarged. Talk to a group just as you would a single person. A group is a collection of John Smiths.

7. Be natural, don't imitate others. Talk to your hearers just as if you expected them to stand up and talk back to you. Be sincere.

8. Carefully prepare the opening of your talk in advance. It should be short, and it should lead into the heart of your subject.

9. The opening should seize attention immediately. Use an exhibit, ask a question, offer startling facts or a striking quotation.

10. Plan your ending carefully. What is said last is likely to be remembered longest. Suggested ways for closing are: summarizing, appealing for action, complimenting the audience, quoting a fitting verse.

11. Have a good beginning and a good ending and put them close together. Always stop before your audience wants you to.

DEDICATION DAY AT CINCINNATI AND WASHINGTON

We won't claim that the man you see in a hurry these days is on his way to the dedication of a treatment plant, but then neither will we claim that he isn't. As a matter of fact, we wouldn't be surprised one bit to have someone hand us a card reading—"Have Dedicatory Speech, Will Travel." What's more, we're all for it because there's hardly a treatment plant built that isn't worth dedicating.

FIGURE 1.—At left, Washington's Plant Superintendent Hugh Schreiber discusses aeration tank operation with David Auld, Director of Sanitary Engineering for the District of Columbia, District Commissioners David Karrick and Robert McLaughlin, and Secretary Flemming (*Washington Post* Photo).

Wastewater treatment plants cost a lot of money to build and they cost a lot of money to operate. The dedication serves to show the public where the money went and where future dollars will go.

Happily now, we are able to report that two recent ceremonies were exemplary events. One was at the Mill Creek Sewage Works in Cincinnati and the other at the secondary treatment plant in Washington, D. C.

The principal speaker on both occasions was Dr. Arthur S. Flemming, Secretary of Health, Education, and Welfare.

Some of the activities of both days are recorded pictorially in Figures 1 through 8.

FIGURE 2.—Flag-raising ceremony at the Mill Creek Works.

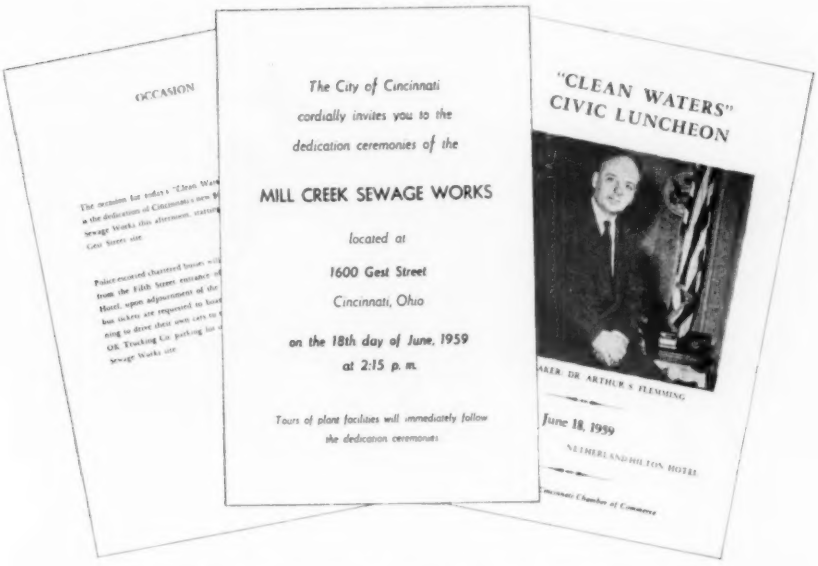

FIGURE 3.—Cincinnati's invitation and luncheon program.

FIGURE 4.—Washington's invitation and program.

FIGURE 5.—Chartered buses shuttled Cincinnati visitors from one end of the plant to the other.

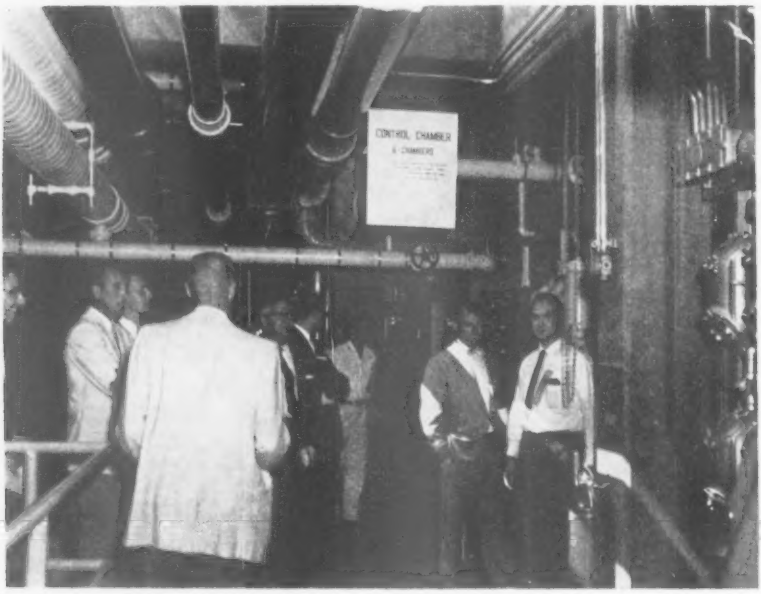

FIGURE 6.—Mill Creek visitors deep in the heart of plant. Note descriptive sign near top of picture.

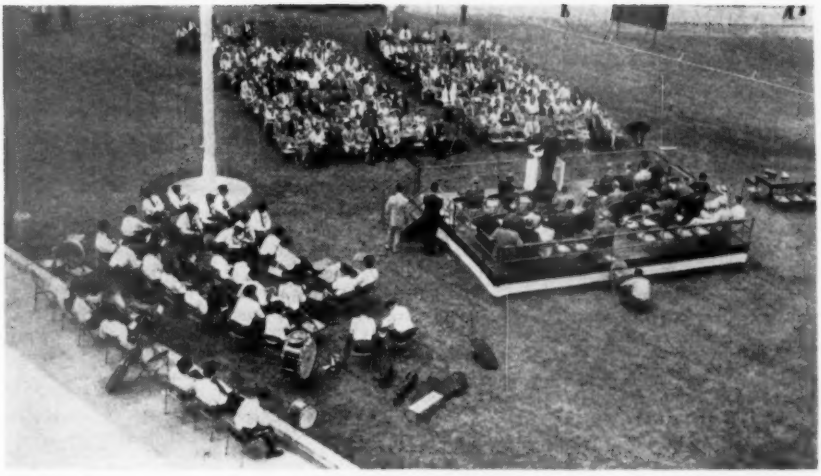

FIGURE 7.—Secretary Flemming making dedicatory address at the new secondary plant in Washington, D. C.

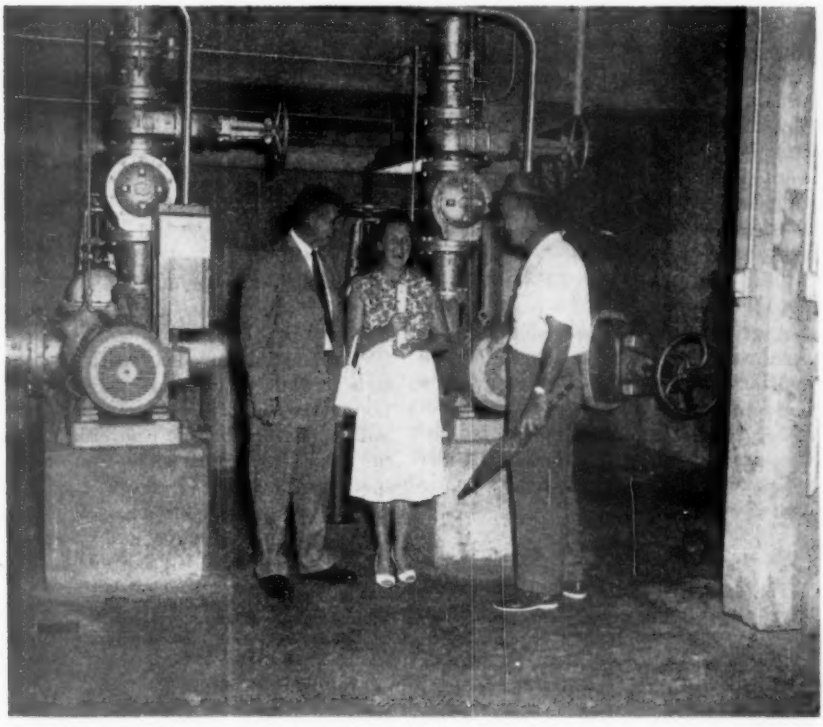

FIGURE 8.—Visitors to the pipe gallery of Washington's new plant. Note descriptive sign on spray water pump.

PLANNING THE DEDICATION OF THE MILL CREEK SEWAGE WORKS

By Arthur D. Caster

Principal Sewage Disposal Engineer, Division of Sewage Disposal, Cincinnati, Ohio

Editor's Note: In the preceding article the results of a well-planned and superbly executed dedication are self-evident. But what that piece doesn't show is the thoroughness of the planning which went into those events. Fortunately, Mr. Arthur Caster has let us in on this secret by chapter and verse, and we are happy to pass it on to you. The secret, briefly, is—HARD WORK.

The dedication of the Mill Creek Sewage Works on June 18, 1959, has been proclaimed by those in attendance as a most successful affair. Its success can be attributed to careful and complete planning, proper coordination, excellent cooperation, and outstanding execution.

Inasmuch as the dedication was a scheduled event of the 33rd Annual Meeting of the Ohio Sewage and Industrial Wastes Conference, the exercises were simple and not too lengthy. This afforded an opportunity for the people at the Conference, as well as other visitors, to view the plant facilities.

Planning

A great deal of time and effort was spent on the planning phase of the dedication. The aim was to get the big jobs out of the way first. Thereafter, time could be concentrated on the smaller jobs and other details which would arise just prior to the dedication date.

Date

The date of June 18, 1959 was established approximately one year prior to the 1959 Conference. The established date was necessarily the target at which all planned activities were aimed. It became the byword of all those interested in the dedication of the plant.

Advance Notices

Advance notices announcing the dedication of the Mill Creek Works were mailed to all contractors and sub-contractors participating in the construction of the plant and also to numerous publications, including newspapers and periodicals. These notices were also sent to various consulting engineers and other people and engineering firms interested in the treatment of sewage and industrial wastes. Notices went all over the United States and to parts of Canada.

Meetings

Meetings were held with interested parties both inside and outside the Division of Sewage Disposal.

One meeting was held with the officials of the Cincinnati Chamber of Commerce so that duties and responsibilities concerning the Conference and the civic luncheon, which was to be sponsored by the Chamber, could be defined properly. As a result of this meeting it was decided that the Division of Sewage Disposal should prepare a brochure in cooperation with the Chamber. In this connection the Division prepared an article recounting the effective and faithful participation of Mr. Hudson Biery in the anti-pollution program. In addition it was decided that the Division of Sewage Disposal would order the neces-

sary buses for transportation from the hotel to the plant site on the afternoon of the dedication. Further, it was decided that the plaque honoring Mr. Biery, Chairman, Stream Sanitation Committee of the Chamber of Commerce, would be ordered at the same time the three other plaques were ordered by the Division of Sewage Disposal. Otherwise, the Chamber of Commerce would carry out all phases of the luncheon, including the invitation of guests, speakers, and all dignitaries and the Division of Sewage Disposal would be responsible for the dedication of the plant. This avoided any conflict of duties.

Three meetings were held with representatives of the contractor in an effort to decide and to determine which facilities would be ready for tours on the afternoon of June 18.

A meeting with the city officials was held to formulate plans for the participation of the Mayor, City Manager, Director of Public Works, as well as the City Council, in the dedication program. Discussion centered around protocol and other important factors.

The officials of the Ohio Sewage and Industrial Wastes Conference were contacted so that the dedication program could be properly oriented with the activities of their meeting.

A few meetings were held with the officials of the Division of Sewage Disposal during which planning assignments were made to cover certain phases of the dedication. These phases were as follows:

1. Brochure. The planning of a brochure for the dedication received considerable attention. Realizing that this would be one of the bigger jobs, more time was spent on this phase than on others. The preparation of the brochure was done by the people in the Sewage Disposal Division.

2. Cleaning of Buildings and Grounds. The first effort made toward a successful dedication was cleaning of the interior of the buildings and also a general policing of the areas adjacent to the buildings which had been turned over to the City. The work started well in advance of the June date. Cleaning of unfinished facilities was the responsibility of the contractor.

3. Transportation. Means of transportation were discussed and assignments made for transportation of guests from the hotel to the plant site and also transportation within the grounds. The first phase would be done with eight city buses, while the second phase would be taken care of by vehicles of the Sewage Disposal Division. It was felt necessary to have the latter in the event that emergency transportation might be required.

4. Tours. A great deal of emphasis was placed on the method, routing, and timing of tours. Several "dry" runs were made to determine the exact time which would be required. As a result of studies and actual participation, it was decided to have two types of tours.

One tour, a walking tour, would start from the southerly end of the plant and take in buildings still incomplete. It would end at a point midway in the project where buses would carry guests to the northerly portion of the site where the facilities were completed. It was decided to have signs at strategic points along the route, and also to have persons give short talks at certain locations. These talks would be given by representatives of Sewage Disposal.

The other type of tour would be a presentation of a moving picture with running commentary, showing the construction of various buildings and facilities necessary in the treatment of sewage. This was done so that anyone not familiar with the treatment process would be given an insight into the principles involved.

Guides for the tours would be members of Sewage Disposal, assisted by

members of the Cincinnati Municipal Supervisors' and Foremen's Association. Orientation sessions for these men were also scheduled.

5. Invitations. More than 950 invitations were sent to various individuals, industrial concerns, and leading dignitaries of the nation, state, and municipalities. These invitations in most cases were hand addressed. Invitations were properly catalogued by groups for ready reference.

A unique feature of the invitation was the inclusion of a map, showing the plant site and the various routes leading to the plant, as well as parking facilities adjacent to the plant site. Invitations were also sent to various manufacturers' representatives. This was done so that they could be present and talk with people who might be interested in their equipment.

6. Communications. It was decided to have two portable walkie-talkie sets, one in the southerly portion of the plant and the other in the northerly portion. Arrangements were made for the procurement of a public address system for the exercises. It was also decided to have a messenger available in the event that an emergency call would be made for anyone attending the dedication.

7. Registration. Plans called for locating the registration booth at the entrance of the plant on Gest Street. Registration would include recording on appropriate forms the person's name, address, and company represented. After registering, each person would be given a brochure, a copy of the *American City* story, and a program. It was also decided that invited guests and those who were on the speaking platform would be given special badges so that proper identification of these people could be made. Four lines for the registering of guests would be made available for smoothness of operation. It was also decided to provide a canopy at the registration location in view of the fact that warm weather could be anticipated in Cincinnati at this time of year. This canopy would provide adequate shade for the registrars.

8. Program. Much thought and consideration were devoted to the planning of a speaking program which would lend dignity to the occasion. A master of ceremonies was selected and invitations were extended to the Mayor, members of the City Council, the City Manager, Director of Public Works, and the City Engineer to participate in the program.

Arrangements were made for recognizing the honored guests and officials of the 26 political subdivisions participating in Cincinnati's sewage disposal program.

After consultation with Chamber of Commerce officials, the opening time for the ceremonies was scheduled for 2:15 P.M. This hour was selected to permit those attending the noon luncheon to get to the ceremonies in ample time.

A clergyman was invited to offer the invocation on this occasion. Arrangements were also made for the presentation and acceptance of two plaques honoring individuals. Plans were also formulated for the participation of the flag-raising detail from the Marine Corps Recruiting Station. The Park Board was asked to furnish greenery for decorating the speakers' platform.

One of the more important steps was the timing of all events so that the entire program would occupy approximately 30 min.

After a further review of the various phases of the program, a requisition for printed programs was forwarded to the purchasing department.

9. Parking. In view of the fact that construction forces would be operating on June 18, the problem of parking was an important factor in the plans. Consequently, the officials of a nearby trucking company were asked if their parking facilities could be used on that day. They readily

consented and put their parking lot in first-class condition. In this connection it was planned to present to each person a notice stating the closing time of the lot. This was done so that the parking lot could be closed shortly after 5:00 PM.

10. Publicity. An endeavor was made to contact all newspapers and radio and TV stations in the area. News releases along with copies of brochures and a program were sent to each. In addition, phone calls were made to invite representatives of these media to visit the plant for further details.

A proclamation was written for the signature of the Mayor declaring the week of June 14 as "Clean Waters Week." A story in the newspapers carried the intent and purpose of this proclamation, which highlighted the dedication. Considerable time was also given to the representatives of the *American City* magazine and to the advertising agency for the Cooper-Bessemer Corporation and other outlets, for individual stories regarding the Mill Creek Plant.

11. First Aid. Because of the possibility of intense heat during the dedication, it was felt that first aid stations should be established on the plant site. Therefore, the fire department was asked to supply personnel to handle such stations. Two stations were established; one in the administration building and the other in the service building.

12. Traffic. Because the plant is located in a relatively high industrial area involving a great amount of traffic, it was decided to contact the police department for assistance in handling the traffic.

13. Roadways. Since new roads were being built on the plant site, it was necessary to communicate with the superintendent of highway maintenance to ascertain if the new roadways would be able to handle traffic within the plant on the afternoon of the dedication. Alternate routes were selected in case tentatively selected roadways were not usable.

14. Equipment Displays. It was decided to use the area between the sludge disposal building and the service building for the display of major equipment used by the Division. In the display were trucks of various types, motor scooters, a motor boat for use on the Ohio River, and other associated equipment.

15. Pictorial Review. It was decided to have pictures taken of the event, including motion pictures. The photographers were instructed to take pictures at various locations so that an over-all record would result.

16. Miscellaneous. Under this subject preparations were made for the manufacture of badges and the necessary signs to be used during the dedication. Badges included those for manufacturers' representatives, hosts, operational personnel, and other officials. Signs were made covering the tours, the various pieces of equipment, the parking lot, first aid stations, and movies.

17. Follow-up. In any endeavor of this type, a follow-up system must be used to see that the planning is properly carried out. This was done at intervals prior to the dedication.

Coordination

Coordination was necessary so that all phases of the program which were assigned to various agencies would finally fit together.

As an example, the coordination between the Division of Sewage Disposal and the Chamber of Commerce, particularly in obtaining the necessary information at the proper time so that the brochure could be sent to the printer for publication, is worth noting. It is also to be noted that requisitions to the purchasing department had to be submitted in sufficient time to permit that department to carry out its responsibilities in getting the neces-

sary materials to the Division of Sewage Disposal prior to dedication day.

A follow-up system similar to that used in the planning phase was used in the coordinating phase of preparation.

Cooperation

The Division of Sewage Disposal experienced excellent cooperation from other departments in the City. The Division has publicly expressed its appreciation of the cooperation displayed by the fire, police, highway, communications, park, and purchasing departments, and also to the Municipal Supervisors' and Foremen's Association. In addition to the municipal departments, the Division had fine cooperation from other firms and individuals as well as from all of the personnel employed in the Division.

Execution

It is believed that the execution of this program was successful because all personnel were assigned a task which was to be performed at a particular time and at a particular place. In the assignment of personnel, a small reserve was maintained in the event illness or inability to perform certain duties befell those with assigned tasks.

The weather on the dedication date was highly extraordinary and this fact in itself is believed to have had a great bearing on the attendance. No last-minute changes were made.

Conclusion

As a fitting climax to a successful undertaking, numerous "thank you" letters were sent to the various organizations and individuals who participated in the program.

SLUDGE FILTRATION AND INCINERATION AT CAMDEN, NEW JERSEY *

By John Frazee

Superintendent of Sewage Treatment, Camden, N. J.

Camden's main sewage treatment plant is located on the Delaware River. The plant is of the primary type and the raw sludge is dewatered and incinerated. Plant design capacity is 53 mgd with an estimated normal flow by 1960 of 46 mgd. Facilities are provided which are intended to serve the purpose of concentrating sludge and at the same time provide a means of determining the digestibility of sludge. They consist of two tanks each having 100,000-cu ft capacity, a floating cover, and heat exchanger. During the first eight months of operation controlled digestion was practiced with very good results. Since that period, however, the tanks have been operated strictly on a storage and concentration basis with a certain amount of unassisted digestion taking place. Vacuum filtration is handled by six drum-type filters covered with 120 × 46 mesh monofilament saran cloth. Three of these cloths have been in use since Apr. 1956. Each of the filters has 250 sq ft of filter area. Lime and ferric chloride are used for sludge conditioning.

It is felt that the equipment furnished for the handling of chemicals is about as efficient as any now available and worth taking time to describe. Ferric chloride is purchased on an an-

* Presented at the 1959 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 22–23, 1959.

hydrous basis and furnished in an aqueous solution in tank car lots. The coagulant concentration varies from 37 to 49 per cent, depending on the temperature at the time of shipment. At the plant it is cut to a 20-per cent solution for use in filtration. Unloading is accomplished by means of compressed air and the chemical is stored in two 8,000-gal rubber-lined tanks in the basement of the sludge disposal building. After the necessary connections are made, an 8,000-gal car can be unloaded in about an hour.

Lime is received in hopper cars and unloaded using a vacuum system. It is stored in three bins on the second floor of the sludge disposal building. From the bins it is fed by gravity directly to the slaking equipment. One man, with the periodic help of an assistant to help change the suction hose from hopper to hopper, can unload a 40-ton car in 12 to 14 hr.

Drying and incineration are handled by two flash-drying and incinerating units. Each of these units is rated at 10,000 lb of filter cake per hour at 70 per cent moisture. Design Btu content of the cake was 5,200 Btu/lb with a volatile content of 52 per cent. Heat dissipation design was 15,600,000 Btu/hr.

Auxiliary heat is furnished by two oil burners operating on No. 5 fuel oil. These burners are of two different sizes and they permit the operator to meet a wide range of fuel demands.

The fuel oil is stored in a 15,000-gal tank equipped with two 5-kw tank heaters. Additional heating units are installed in the fuel oil lines which maintain a temperature of 125°F at the oil burners.

The ash residue is removed from the furnaces by screw conveyors which discharge into a hopper. Here the ash is converted to a thin slurry and pumped to a lagoon approximately 600 ft from the building.

Startup Problems

General

The year 1958 marked the first full year of operation of the sludge disposal facilities. For 18 months previous to Sept. 1957, the operation was a series of starts and stops, shutdowns, breakdowns, and more or less general confusion. This was true with the filters, chemical feeders, and incinerators and all pertinent equipment in the sludge disposal building. Personnel training, in addition to the normal startup problems, added to the general unfavorable situation. In the first 14 months, 10 different operators were assigned to the incinerators and replaced either by their request or otherwise.

Tannery Waste

For the best operation of the flash drying units, i.e., at highest efficiency, a steady, balanced load should be maintained. When operating at or near rated capacity, any change in the amount or characteristics of the filter cake is immediately reflected in the drying units. This was one of the first problems that had to be reckoned with. During the initial startup of the plant, several large sewers in Camden held large accumulations of hair from tannery wastes. This material ended up at the plant and eventually in the sludge pumped to the filters. The cake resulting from this sludge was roughly 1 in. thick and of the consisteney of a felt rug. It peeled off the filters onto the conveyor belt and folded over three or four thicknesses until it became heavy enough to tear loose. It then would reach the incinerators as a slug which exceeded the design capacity. One minute there would be an overload, the next minute nothing at all. The operator was under constant pressure to maintain a balanced condition with his various controls. This necessitated stationing men at the filters to cut the blanket loose and another man

at the cake breaker to equalize the load on the conveyor belt. Many types and shapes of cutters and other gadgets were tried in an effort to equalize the flow of filter cake to the drying units.

This same cake also created a problem in the drying units. The gunite-lined cyclone with its rough surface encouraged the collection of light, fluffy, hair-like material. The accumulated material soon bridged and created a plug. The time required to develop a plug varied from 2 to 4 hr. The first attempt to correct this condition consisted of hanging a chain in the center of the cyclone. This worked fairly well until it wore through and a section of it fell into the air lock. Next, it was decided to line the lower half of the cyclone with stainless steel and this seemed to solve the problem. This liner has since been removed because the hair content is no longer a problem. As the hair problem disappeared the difficulty of maintaining a constant load became less troublesome and the operation of the drying units became easier. Operation was also improved by installing automatically controlled dampers. Previous to this, the dampers were manually controlled and the operator tended to over-control so that constant correction was necessary. With automatic controls, temperature changes are held to a close tolerance, resulting in a uniform and smooth operation.

High Heat Value of Cake

Another problem was the very high Btu content of the filter cake. Design figures for the units had been based on a filter cake having a Btu content in the neighborhood of 9,000 to 11,000/lb of volatile solids; the material being handled varied from 14,000 to 18,000 Btu/lb. This fact, however, did not come to light until after the problem of trying to load the furnace according to the specifications on pounds of moisture to be evaporated and dry solids to be burned was causing great difficulty. Temperatures were constantly at the critical point making it necessary to install water sprays at various points. In view of this it was decided to have some Btu tests run and thus the high heat value of the solids was discovered. These tests were used as an added aid in determining loading limits. Their value has been such that heat-value tests have become a part of the operating program.

Among other odd problems was the presence of a material in the sludge later determined to be of an asphaltic origin. The first indication of the problem was evident in the difficulty experienced in maintaining slingers on the rotating bars in the cage mill. These slingers would wear very rapidly and permit a buildup in the cage mill which would act as a brake and stall the cage mill. This would necessitate a shutdown to open and clean the cage mill. Originally a 3- to 4-hr shutdown could be expected but the operators became so proficient that shutdown time was eventually cut to 1 hr. To help prevent emergency shutdowns with the resultant possibilities of a cage mill filled with sludge, ammeters were purchased and connected into the cage mill motor circuit. The operator was instructed to shut down when the load current started to rise and reached a certain point. In this manner an orderly shutdown was obtained and all the cake was taken from the filters. After considerable preliminary work in attempting to identify the material that was causing the trouble, it was decided to make a plant-to-plant survey when it was realized that during this time things had been running smoothly for some time. Routine inspections were showing that the buildup was being kept under control and that wear on the slingers was no more than a normal operation would cause. Due to this factor the plant survey was held up to await further developments. To date there has been no recurrence of this problem.

Operating Problems

In addition to the unusual startup problems all routine problems have been encountered. One such problem is the blinding of the filter medium. During 1958, 325 gal of muriatic acid, diluted 50 per cent with water, was used for cleaning filter cloths. This was applied with long handled scrub brushes which is admittedly dangerous, messy, and inefficient. At the present time a spray rig is being built. The rig consists of nozzles set in a manifold. In addition, daily washings with the water sprays and periodic washings with a detergent have helped. The detergent used is triethanolamine alkyl aryl sulfonate purchased from a local chemical house. This is diluted 1,200 to 1 and the filter drum is rotated in it for several hours.

Late in the fall of 1957 a two-shift operation was set up. Until this time, operation had been somewhat sporadic and sludge seemed to be in every available spot. The holding tanks were full and the settling tanks in use were little more than poorly operated Imhoff tanks. It was imperative, therefore, that every effort be made to maintain an accelerated schedule to relieve the situation.

The operating schedule set up consisted of two, four-man shifts; two men for the filters and two men for the incinerators. One shift operated from 7 AM to 3 PM and the second shift from 3 PM to 11 PM. Allowing one hour in the morning for startup and one hour at night for cleanup, a 14-hr working day could be maintained. The hour in the morning is usually needed only on Monday morning since for the balance of the week burning is usually started in from 35 to 45 min. This time is always dependent on the ability of the filter operators to get the filters rolling as the incinerator is invariably ready. The hour allowed for shutdown is used to thoroughly clean the filtering equipment.

During operation the incinerator operator is the man responsible for determining the number of filters to be used and the amount of filter cake needed. It is the responsibility of the incinerator operator to interpret the readings on his gauges so that he can keep the filter operators correctly informed of operating conditions in order that they might produce the proper amount of filter cake for the most efficient loading of the drying units.

At the beginning of 1958 the sludge load averaged 80,000 gpd of about 6-per cent solids. However, a certain percentage of this was what might be referred to as a recirculated sludge. The supernatant from the sludge holding tanks contained a heavy concentration of solids which was returned to the inlet of the plant and put through the settling tanks, along with the incoming flow. A large share of this would again be removed in the settling tanks and the cycle would repeat again. It is now expected, however, that this accumulated backlog can be eliminated.

Operating Procedure

On Mar. 1, 1958, a revised system of records was installed to accumulate operating data which it is hoped will shed light on ways to improve operating efficiency. This is still under continual revision as various problems arise. However, the operating data which follow are as accurate as present practice and facilities allow. It is known that there have been long periods of time when the filter-cake scales were in error. By operating the drying equipment with temperatures as a controlling factor, estimated loadings showed the units were being loaded within the design capacity. At other times, the availability of sludge became a limiting factor and all available filters were pressed into duty to keep one of the two incinerator units operating.

It should be pointed out here that all operations described are based on the use of only one of the two incinerating units and alternating the operation

monthly. This method of operation is felt to be the most economical at this time. Several reasons support this view: first, power costs which include a demand factor would be materially increased if two units were run on a part time basis; second, additional labor and materials would have to be expended to maintain a higher production of filter cake, and there have been times when, due to the sludge characterestics, it would have been impossible to operate two incinerators with the yield from all six filters; third, by alternating operation of the incinerators the maintenance force can proceed with a routine program of inspection and repair of necessary items during the normal work day.

Operating Data

Data in Table I show how the varying sludge characteristics affect operating conditions.

On July 15, 1958, a 14-hr run disposed of 111,000 lb of filter cake. Moisture content averaged 69.7 per cent, 77,446 lb of water was evaporated or an average of 5,300 lb/hr which is 78.5 per cent of the design factor of 7,000 lb/hr. Dry solids consumed amounted to 33,667 or 2,400 lb/hr which is 80 per cent of the design figure of 3,000 lb/hr. The Btu value of the filter cake on this day was 2,585, with only 37.7 per cent volatiles. Fuel consumption necessary to maintain combustion amounted to 771 gal of oil. The excessive amount of oil used brings the heat release up to 91 per cent of design figures.

The run of Apr. 24, 1957, was a short run of only 4¾ hr. It was selected for inclusion in Table I because of the high heat content of the sludge cake. Although no attempt was made during this run to load the incinerators to capacity, the difference in oil consumption is immediately apparent. During the run of July 15, 1958, average oil consumption was 55 gal/hr; on Apr. 24 the consumption was only 4 gal/hr. Despite the short run and low loading creditable efficiencies in water evaporation and heat release were attained.

The last day, June 10, 1957, was chosen because the sludge cake was very close to the type on which the design of the incinerating units was based. This was a 7-hr run with an average load of 9,300 lb/hr. Oil consumption again was low, totaling only 16 gal.

Table II is a tabulation of general operating data for 1958. The power figures for the incinerator include the operation of auxiliary equipment such as oil tank and line heaters, deep well pump which furnishes water for ash removal, oil pumps, and ash pumps. Filtration power is estimated on the basis of connected motor ratings and time of operation. This figure is undoubtedly high because all the motors involved operate for the most part well below full-load values.

Chemical use is calculated daily

TABLE I.—A Comparison of Operating Efficiencies with Design Factors

Date	Run (hr)	Filter Cake (lb)	Moisture (%)	Volatiles (as % of TS)	Heat Value (Btu/lb)	Water Evap. (lb)	Dry Solids Consumed (lb)	Aux. Fuel (gal)*	Per Cent of Design		
									Water Evap.	Dry Solids Consumed	Heat Release
7/15/58	14	111,113	69.7	38	2,585	77,446	33,667	771	79	80	91
4/24/57	4.75	32,000	74	55	7,000	23,700	8,300	19	72	59	72
6/10/57	7	65,513	70.5	51	5,000	46,046	19,267	16	95	91	87

* Btu value of oil, 149,000 Btu/gal.

TABLE II.—Summary of Operation of Sludge Disposal Facilities

Item	Amount
Total days of operation	227
Total hours of operation	2,785
Filter cake produced (1,000 lb)	19,918
Filter cake produced per hour (lb)	7,200
Filter cake moisture (%)	70.6
Dry solids in filter cake (1,000 lb)	5,852
Btu content of filter cake:	
Avg	3,417
Max	4,992
Min	2,552
Lime used (1,000 lb)	853.7
Ferric chloride used (1,000 lb)	316.8
Auxiliary fuel:	
Warmup (gal)	8,821
Burning (gal)	119,000
Power for incineration (kw)	442,000
Power for filtration (kw est.)	249,000

from work sheets turned in by the operators and is based on counter readings on the equipment. Periodic checks of filter-cake scales have revealed overweighing errors as great as 15 per cent. Rather than attempt to improve the over-all picture by using a correction factor, which at best could be called an educated guess, the scale figures as recorded have been used.

Tables III and IV are a summary of cost figures for the year 1958. These figures are based on the data in Table II. In Table III oil consumption includes both warmup oil and oil consumed during burning. Labor costs are for operating personnel only.

A comparison of Camden's costs, as shown, with other cities whose data are available suggests that cost reductions at Camden are a distinct possibility. The experience gained during the past year and the data accumulated provide a starting point for continued improvement in operational efficiency.

TABLE III.—Operating Costs for Filtration and Incineration During 1958

Item	Filtration	Incineration
Labor	$ 9,352.40	$ 9,352.40
Power	2,006.40	5,310.00
Fuel	—	11,366.06
Lime	8,293.12	—
Ferric chloride	15,665.50	—
Total	$36,307.42	$26,028.46

One of the main items of interest to all superintendents of sewage treatment plants is the cost of maintenance. It is a rather well accepted fact that city fathers are prone to overlook budgetary requests for maintenance once the equipment is installed. Sewage is in itself inherently destructive to almost any material it comes in contact with, whether through abrasion, corrosion, or just general deterioration. The addition of highly corrosive acids and the use of high temperatures do not tend to alleviate these characteristics.

In spite of these factors it is not felt that maintenance costs of the filtering and incinerating equipment at Camden have been excessive. As mentioned previously, three of the original filter cloths installed in Apr. 1956 are still in daily use. Several weigh belts have been renewed on the lime slakers and minor repairs to the ferric chloride pumps have been made.

TABLE IV.—Unit Operating Costs for Filtration and Incineration During 1958

Item	Cost
Cost of disposal (per ton of dry solids)	$21.29
Cost of filtration (per ton of dry solids)	12.40
Cost of incineration (per ton of dry solids)	8.89

In the past year a set of burner tile was installed in each incinerator, some fifty bars were renewed in the cage mill, and after a close inspection of the brick work in one of the units, approximately two bags of patching refractory were used to cover up some minor spalling. In addition, some four or five flights on the ash conveyor were replaced.

Maintenance of the equipment is based on a program which assigns specific duties to each operator. General

maintenance work is handled by the chief mechanic and his crew. All motors are the responsibility of the electrician.

Summary and Conclusions

The experiences at Camden point to the fact that the disposal of sludge is a controlling factor in the efficiency of any sewage treatment plant. Unless a means of disposing of sludge as it accumulates is available the entire purpose of the plant is defeated.

The disposal of sludge is an expensive operation by any method now in use in large installations.

The equipment in use at Camden has a high degree of flexibility and is readily adaptable to changes in operating demands.

With additional experience in filtration and incineration it is believed that considerable improvement in efficiency and cost reduction can be attained.

RAPID STARTUP OF DIGESTERS AT A SMALL TREATMENT PLANT * †

By Harold E. Orford, Desmond D. Egan, and Joseph P. Foley

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Tarrytown, N. Y., is served by a primary sewage treatment plant having one primary and one secondary digester. For many years only one digester was used since it seemed to meet the digestion needs of the plant adequately.

Through a series of unfortunate circumstances, the single digester in use went sour, gas production stopped, and the process failed. When the primary digester, which had not been in use, was placed in service without using lime, it also went sour before digestion and gas production could be initiated. In addition, the heavy sludge and scum accumulation damaged the sludge heating coils. Inasmuch as an operating digester was needed urgently, it was decided that the primary digester should be emptied, repaired, and started as quickly as possible, preferably under full load.

There are two schools of thought concerning the proper method of starting sludge digesters in the absence of adequate amounts of digested sludge for seed. The first advocates startup without lime addition under a very low sludge load (10 per cent of design capacity or a volatile solids load of not more than 10 lb/day/1,000 cu ft). The portion of the sludge not pumped to the digesters must, of course, be disposed of separately or discharged with the effluent.

The second school of thought subscribes to the belief that digesters should be able to be started under full load by maintaining pH control with lime and that it should not be necessary to bypass solids except possibly with heavily loaded high-rate digesters.

Low-Load Startup

Schlenz's (1) recommendations for starting a digester are, in part, as follows:

1. *Startup Volume.*—Use least capacity available. Start one digester

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† Presented at the Spring Meeting, New York Sewage and Industrial Wastes Assn.; Upper Saranac Lake, N. Y.; June 8-9, 1959.

at a time. Fill tank only sufficiently to float the cover.

2. *Seeding Culture.*—Not necessary but will help. If seeded, add enough seed sludge to give 0.5-per cent sludge solids in tank liquid.

3. *Sludge Feed.*—Feed gradually. Add no more than 10 per cent of anticipated sludge volume each day.

4. *Contents Recirculation.*—Recirculate digester contents (bottom to top) at least 2 hr each day.

5. *Volatile Acids Determination.*—Determine volatile acids daily before adding feed sludge. Volatile acids should not be over 2,000 mg/l. If volatile acids concentration shows continued increase over 2,000 mg/l, or digestion does not start, reduce or stop feed of raw sludge.

The difficulties in starting the digesters at the Little Miami Sewage Works in Cincinnati are described by Backmeyer (2). In their first attempt, raw sludge was pumped to the primary digester without using lime for pH control at a volatile solids loading of about 50 lb/day/1,000 cu ft. Naturally, acid digestion set in, the pH dropped to 5.3, and the digesters were filled with sour sludge. A new start was then made on a primary digester employing the Schlenz method of digester startup control, using 3,000 cu ft of digested sludge from another plant in the 80,000-cu ft digester. For the first 40 days the volatile solids loading was held down to 10 lb/day/1,000 cu ft. Recirculation was practiced 4 to 6 hr daily and the temperature was held at 85°F. Whenever the volatile acids concentration rose above 1,800 mg/l sludge feed was stopped until it dropped.

After 60 days, the volatile solids loading was increased to 50 lb/day/1,000 cu ft, and after 100 days, to 80 lb/day/1,000 cu ft. Forty days after startup, the pH was 6.3. In 100 days it had risen to 7.1. It was concluded that the Schlenz method of startup control enabled digestion to be established within 60 to 100 days.

High-Load Startup

When lime can be used effectively for pH control from the beginning of startup, digestion can be established in 20 to 40 days under full digester loading. Van Kleeck (3) states that for over 25 years plant operators in Connecticut have been given a guide for digester startup from the Connecticut State Department of Health and that, when these instructions are followed, burnable gas can be produced in 30 to 40 days.

Van Kleeck's method for digester startup is essentially as follows:

1. Fill digester with sewage and water.
2. Heat contents to 85°F.
3. Daily (or more often) add fresh raw solids together with hydrated lime of high oxide content.
4. Add 10 to 15 lb of lime per 1,000 connected population or enough to maintain pH at from 6.8 to 7. If pH drops below 6.8 more lime should be added. Check pH of digesting sludge daily at several levels after recirculation, especially in the bottom sludge.
5. Circulate sludge from top of digester to the bottom, or to the middle, several hours per day.

At the 1957 Operators' Forum, Sawyer (4) gave his opinion that digesters should start under full load and be able to establish digestion. His suggestions for startup were similar to those given by Van Kleeck (3).

Cassell and Sawyer (5) studied in the laboratory the startup of high-rate digesters. Using mixed primary and waste activated sludges, they found that digestion could be initiated in 20 days with burnable-gas production about half of what it is after normal digestion is well established. The digesters were continuously mixed, and lime was added from the beginning to maintain the pH between 6.8 and 7.2.

TABLE I.—Capacities of Treatment Units

Population equivalent	11,500
Flow (mgd)	1.15
Primary settling:	
Avg det. (hr)	2.6
Surface overflow rate (gpd/sq ft)	930
Digester capacities:	
Primary (cu ft)	14,350
Secondary (cu ft)	14,350
Total (cu ft/cap)	2.5
Sludge drying beds (sq ft)	4,656
Sludge drying beds (sq ft/cap)	0.4

For the digester receiving the highest loading (volatile solids loading of 160 lb/day/1,000 cu ft), the volatile acids content went as high as 5,800 mg/l without causing failure, even though the raw sludge was continuously fed each day on a 20-day-detention-period loading. After 29 days, lime addition was not necessary, and up to that time the total lime used was 87 lb/1,000 cu ft.

Tarrytown Startup

The basic data concerning the treatment plant units, given in Table I, shows the Tarrytown plant to be a conventionally designed small primary sewage treatment plant. The settling tanks have a fairly high surface overflow rate; and judged by present day standards the covered sludge drying beds are somewhat undersize.

In order to simplify startup procedures on the one digester available, it was decided that a constant amount of sludge (400 cu ft/day) would be fed. The average sludge loadings are given in Table II. The analytical control was also simplified to the point where only colorimetric determinations of pH were made. The following suggestions for starting the primary digester were made to the operating personnel:

1. Fill the floating-cover digester with sewage and bring the temperature up to at least 90°F before adding sludge. Maintain sludge temperature between 90 and 100°F.

2. Add the full load of raw sludge (400 cu ft/day) to the digester and, simultaneously, add hydrated lime through the lime feeder.

3. Recirculate sludge from the bot-

TABLE II.—Primary Digester Startup Loading

Raw sludge volume (cu ft/day)	400
Detention period (day)	36
Dry solids fed (lb/day)	1,250
Volatile solids fed (lb/day)	820
Volatile solids fed (lb/day/1,000 cu ft)	57

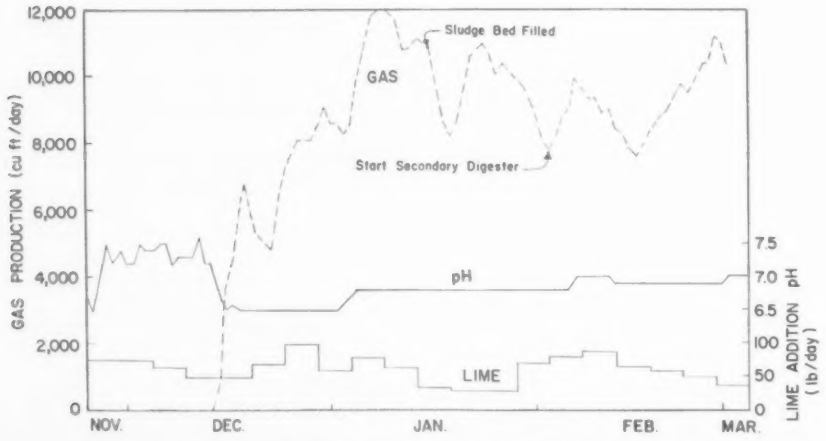


FIGURE 1.—Gas production, pH, and lime added during digester startup.

TABLE III.—Sludge Analyses after Initiation of Digestion

Item	Date			
	Dec. 23	Feb. 3	Mar. 9	May 29
pH	6.7	7.1	—	7.1
Volatile acids (mg/l)	—	1,290	2,570	700
Alkalinity (mg/l)	—	—	2,000	2,350
TS (mg/l)	7.7	5.7	6.5	6.9
Ash (%)	42.3	47.5	53	—
VS (as % of TS)	57.7	52.5	47	—

tom of the digester at least 2 hr each day (preferably 4 hr), adding lime until daily lime dose is added.

4. Take sludge sample after about 1 hr of recirculation for pH determination. Maintain pH of digesting sludge between pH 7.0 and 7.2, if possible, by adjusting lime dosage.

The first sludge was put into the digester on Nov. 14, with the water in the digester at 98°F and the pH at 7.2. By Nov. 26, the 12th day, the pH had dropped slowly to 6.5 and the temperature went to 96°F. At this time, the operators were ready to increase the lime feed when there was a sudden, unexplained increase in pH to 7.5. These changes are shown in Figure 1, which shows the gas production, pH, and lime addition starting with the 11th day, Nov. 25. The gas production curve has been somewhat smoothed by using a four-day moving average.

Gas production started suddenly 30 days after the first sludge was introduced. Within 2 days after the first gas production, it was possible to burn the gas in the boiler, and within 2 weeks, full gas production was achieved. Some additional information concerning the condition of the digesting sludge is given in Table III. As would be expected, the volatile solids content of the sludge continued to decrease after gas production started. The increase in volatile acids concentration to 2,570 mg/l on Mar. 9 gave some concern, however, the pH and alkalinity were being maintained by the continued addition of a small amount of lime and there was no danger of the digester going sour.

By Feb. 3, the secondary digester was cleaned, repaired, and ready for service. Transfer of sludge from the primary digester was begun and the digestion system was placed on a two-stage basis.

Conclusions

It is possible to start conventionally loaded sludge digesters under conditions of full-design load.

To start a digester under full-load conditions (a) the pH of the digesting sludge should be kept between 7.0 and 7.2 by daily additions of hydrated lime, and (b) the digesting sludge should be recirculated daily from the bottom of the digesters; if possible, the volume of sludge recirculated should be 3 to 4 times the daily raw sludge addition.

References

1. Schlenz, H. E., in "1957 Operators' Forum." THIS JOURNAL, **30**, 4, 585 (Apr. 1958).
2. Backmeyer, D. P., "How to Avoid Sour Digesters." *Water and Sewage Works*, **102**, 10, 369 (Sept. 1955).
3. Van Kleeck, L. W., "Start-Up of Separate Sludge Digesters." THIS JOURNAL, **30**, 3, 312 (Mar. 1958).
4. Sawyer, C. N., in "1957 Operators' Forum." THIS JOURNAL, **30**, 4, 585 (Apr. 1958).
5. Cassell, E. A., and Sawyer, C. N., "A Method of Starting High-Rate Digesters." THIS JOURNAL, **31**, 2, 123 (Feb. 1959).

TIPS AND QUIPS

Boat Pollution Control *

The Outboard Boating Club of America has recently issued a "Model Act on Sewage Disposal from Boats" as a unit of its omnibus boating code. This action was taken in recognition of the importance, especially to the pleasure-boat industry and the participating public, of keeping recreational waters free of pollution. The Club is cognizant of the conditions resulting in certain lakes and coastal basins from the unregulated discharge of sewage from boats and refers to the availability of inexpensive devices, attachable to marine toilets, for treating the sewage.

The model law is based substantially on the boat pollution control act passed by the State of New Hampshire in 1957. This statute, which became effective on December 31, 1958, also formed the basis of a model law proposed by the Council of State Governments for consideration by state legislatures. As an introduction to its suggested legislation the Council said: "In some of the states, recreation and vacation facilities have become a major industry. Lakes and rivers rank as primary attractions among such facilities. If polluted, they immediately lose their attractiveness and become a positive menace. Hence . . . [there is a] need for early and effective action against potential blight caused by careless sewage disposal."

Indirect Effects of Wastewater on Fish †

Polluting effluents may cause the death of fish by asphyxiation or by poisoning; even if they do not do this, however, they may seriously damage a fishery in other ways. For example, salmon and trout require clean gravel for spawning and the deposition of organic matter or mud on this will render it unsuitable. Both dissolved and insoluble constituents of effluents, through their action on the plants and invertebrate animals in streams, may reduce or alter the supply of fish food available. It may be—though little quantitative evidence is available—that fish will not occupy stretches of a river in which there is more than a certain concentration of substances which they find obnoxious. It has been thought that they may leave water which is at too high a temperature—usually because of the discharge of heated cooling water; research on this point is at present in progress. Some substances may cause tainting of fish and thus reduce their market value; the most frequent complaint is of tainting of salmon by phenolic substances. In general, much less is known about these indirect effects than about the more direct effects of pollution in causing the death of fish, although again our knowledge is confined principally to the effects on adult fish rather than on fry and eggs.

AEC Orders Licensees to Improve Safety of Mill Operations

The Atomic Energy Commission has issued follow-up orders to the operators of five uranium processing mills in a further step to assure that concentrations of radioactive material in mill areas and in wastes discharged into streams are brought within permissible limits established in Commission regulations.

Under the new orders, performance is made a condition of the companies' licenses to possess and process uranium ores.

* From the May 1959 *Newsletter* of the New England Water Pollution Control Commission.

† From *Notes on Water Pollution* (Sept. 1958).

The plants affected are the Uravan, Colo., and Green River, Utah, mills of Union Carbide Nuclear Company; the Durango, Colo., mill of Vanadium Corporation of America; the Maybell, Colo., mill of Trace Elements Corporation (a unit of Union Carbide Corporation); and the Salt Lake City, Utah, mill of Vitro Uranium Company.

Corrective actions planned include improved control procedures for the discharge of wastes into streams; further use of settling ponds to reduce the concentrations of toxic and radioactive materials in mill effluent; equipment additions and modifications to reduce mill dust including use of mist sprays to wet down uranium, and use of industrial vacuum cleaners, air ducts, and dust collectors. The mills will conduct improved survey programs to determine the effectiveness of measures taken to reduce dust and, where necessary, to lower the concentrations of radioactive materials, including radium, discharged into streams.

Some corrective measures have already been accomplished and others will be carried out in the next few months.

In a related action, the Commission has issued a letter order to the Uranium Reduction Company, directing the company to submit a detailed plan for bringing operations at the Company's Moab, Utah, mill into compliance with licensing regulations.

ORSANCO Asked to Intervene in Huntington Case *

West Virginia's commissioners on the Ohio River Valley Water Sanitation Commission have asked that agency to intervene in the longstanding dispute between the State Water Resources Commission and the city of Huntington.

The Commission ordered the City in 1949 to cease polluting the Ohio and Guyandotte Rivers. The case bounced up and down from the Cabell County Circuit Court to the State Supreme Court until 1953, when the Supreme Court ruled to uphold the validity of the Commission order. In 1955, the Commission sought to indict officials of the City for failure to comply with the Commission's order; however, the Cabell County Grand Jury refused to return an indictment.

Construction on the project finally did get started in 1957, but the City has now proposed a pay-as-you-go plan which would require until about 1969 to complete the project. At its meeting on April 16, 1959, the Commission denied the City's request for any additional time other than that required for the immediate issuance of bonds to finance construction of the system.

At the June meeting of the Ohio River Valley Water Sanitation Commission, West Virginia asked that agency to step into the case since it, too, had served notice on the City in 1952 to cease pollution of interstate waters. On June 18, 1959, the Ohio River Commission directed the city of Huntington to present a reasonable plan of action prior to October 1, 1959. Unless this is done, the Ohio River Commission stated that it would initiate such procedures as it may deem necessary to bring about compliance by the City with the requirements of the interstate compact.

Under the terms of the compact, the Ohio River Valley Water Sanitation Commission may issue orders after holding a hearing to establish the fact of pollution. The compact reads that ". . . Any court of general jurisdiction or any U. S. District Court in any of the signatory States shall have the jurisdiction, by mandamus, injunction, specific performance or other form of remedy, to enforce any such order. . . ."

* From *West Virginia Waters* (June 1959).

News and Notes

Of Persons and Activities in the Wastewater Field

Bernard S. (Bernie) Bush, Regional Sanitary Engineer of the Pennsylvania Department of Health, died in August. He had served as Secretary-Treasurer and later as President of the Pennsylvania Sewage and Industrial Wastes Association. At the time of his death he was one of the Pennsylvania Directors on the Federation Board of Control.

Paul A. Harlamert has become a partner in the engineering firm of Jones, Henry and Williams, Toledo, Ohio.

Charles Yeomans, co-founder and Chairman of the Board of Directors of **Yeomans Brothers Company,** died recently.

Dr. H. Heukelekian, Head of the Department of Sanitation at Rutgers University and Chairman of the FSIWA Research Committee, toured several European countries during the summer. His trip included technical visitations and professional contacts in the following countries: Czechoslovakia, Russia, Sweden, Norway, and Denmark.

C. E. Keefer has been appointed Sewerage Engineer for the city of Baltimore, Md. He has been Assistant Bureau Engineer in recent years.

N. Young DuHamel, Jr. has been elected Vice-President of sales and advertising for Centerline Corporation, a subsidiary of Raymond International, Inc., New York.

William E. Dobbins and **Donald J. O'Connor,** Professors at New York University and Manhattan College, have been awarded the American Society of Civil Engineers' Rudolph Hering Medal for their paper, "Mechanism of Reaeration in Natural Streams."

Alden E. Stilson & Associates, Limited of Columbus, Ohio, announced that **John C. Bumstead** has joined the organization as an Associate Engineer.

Gustav J. Requardt of **Whitman, Requardt & Associates,** Baltimore, Md., was named an Honorary Member of the American Society of Civil Engineers at its meeting in Cleveland.

Harvey F. Ludwig, President, Engineering-Science, Inc., consulting and research engineering firm with headquarters in Pasadena, Calif., has announced the opening of a San Francisco Bay area office and laboratory at 4144 Telegraph Avenue, Oakland, Calif.

Lawson D. ("Deac") Matter, Chief of the Pennsylvania State Health Department's water supply section, retired recently after 40 years of uninterrupted service. He was on the Federation Board of Control during the late 1940's.

Ben Benas, former Superintendent of the Bureau of Sewer Repairs and Sewage Treatment, San Francisco, has been appointed Chief Purchaser for the City and County of San Francisco, Calif.

John M. Robertson has been named Manager of Drainage and Allied Products Sales of **Armco Drainage and Metal Products, Inc.,** Middletown, Ohio.

W. B. Williams has been named Manager of the new sanitary sales office of Dorr-Oliver Incorporated in Winter Park, Fla.

Clarence I. Sterling, Jr. has transferred from the Massachusetts Department of Public Health as Chief Engineer and Director of the Division of Sanitary Engineering to the position of Chief Engineer of the Massachusetts Water Resources Commission in Boston.

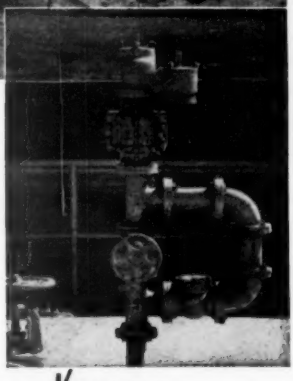
Don T. Kearby has been appointed sales manager of the Texas Vitrified Pipe Company, Mineral Wells, Tex.

Robert L. Rice, former Director and Vice-President of **Fischer and Porter Company,** Hatboro, Pa., has become Vice-President in charge of the Philadelphia office of Lancy Laboratories whose headquarters are at Zelienople, Pa.

Richard Hazen of **Hazen and Sawyer,** New York; and **W. H. Wiseley,** Executive Secretary of ASCE, were among those appointed consultants to the Council on Engineering Affairs of Manhattan College.

Burton A. Scheidt has been appointed Chief Engineer of the Metropolitan Sanitary District for Greater Chicago.

Photos courtesy Dorr-Oliver



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Asbestos-Cement Pipe—Transite pipe is now available in crushing strengths of 1,500, 2,400, 3,300, 4,000, and 5,000 psi, and in diameters ranging from 6 to 30 in.—Johns-Manville Corp., 22 East 40th St., New York 16, N. Y.

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Plastic Gloves—Polyethylene gloves that are rugged enough to be reusable and inexpensive enough to be disposable are available in large, medium, and small sizes. The gloves are packaged in rolls. Twelve-glove to 1,000-glove rolls can be selected. The price in rolls of 1,000 is about 3 cents per glove.—Plasticsmith, Inc., Chicago Daily News Building, Chicago, Ill.

Flow Tube—A plastic insert-type Dall flow tube is announced for metering ordinary liquids, gases, as well as acids, alkalies, and slurries.—Builders-Providence, Inc., 345 Harris Ave., Providence 1, R. I.

Sewer Design Slide Rule—A patented sewer design slide rule based on the Chezy formula, $V = C\sqrt{RS}$, with Kutter's formula being used to determine C, is being marketed by Irving Goldfien, 1708 W. Capitol Drive, Milwaukee 6, Wis.

Compressor—A new line of rotary compressors has been introduced by Fairbanks, Morse and Co., Chicago, Ill. The compressor is a two-impeller, helical-lobe type, axial flow, rotary machine (Figure 1). There is no metal-to-metal contact between impellers or with the surrounding casing, making it unnecessary to lubricate the impellers. Completely oil-free air or gas is assured. The compressor is based on a Swedish design that has been in European service.

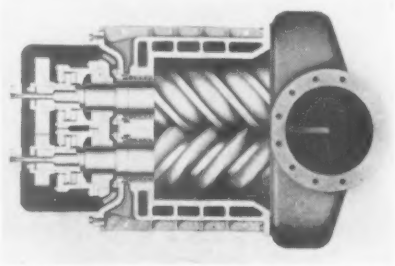

FIGURE 1.—Rotary compressor.

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Proceedings of Member Associations

TEXAS WATER AND SEWAGE WORKS ASSOCIATION

The Texas Water and Sewage Works Association held its Annual Meeting at the Memorial Student Center, Texas A. & M. College, College Station, Tex., Mar. 1–6, 1959. The meeting was held in conjunction with the 41st Texas Water and Sewage Works Association's Short School. Registration totaled 812.

A full program directed at many kinds of wastewater problems was presented. Panel discussions were utilized to good advantage. Among the subjects discussed were: research in the wastewater field; materials, methods, and inspection for sewer construction; lift station design and maintenance; sewer maintenance; filter fly control; sludge digestion and disposal; effluent reuse; problems surrounding relocation of sewers; industrial wastes; and safety in wastewater works.

At the business session luncheon Federation Secretary Ralph E. Fuhrman discussed the forthcoming Federation Annual Meeting and presented the Bedell Award for distinguished service to Roger Moehlman, Sanitary Engineer, Harris County Health Department, Houston. The Hatfield Award for outstanding achievement in treatment plant operation went to S. L. Allison, Superintendent, Sewage Treatment Plant, Corpus Christi.

In addition, the Texas Section made the following awards for unique activities and accomplishments:

(*Continued on page 450a*)

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The following officers were elected for the year 1959–60 to serve the Sewage and Industrial Wastes Section of the Texas Water and Sewage Works Association:

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1st Vice-Chairman: Cecil Williams, Dallas.
2nd Vice-Chairman: John Wold, Houston.
Secretary: V. M. Ehlers,* Austin.
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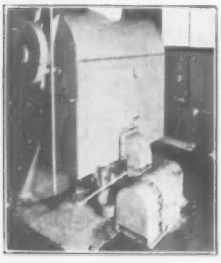

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MARYLAND–DELAWARE WATER AND SEWAGE ASSOCIATION

The 32nd Annual Conference of the Maryland-Delaware Water and Sewage Association was held at the Commander Hotel, Ocean City, Md., June 4–5, 1959. One hundred eighty registrants were in attendance.

In one of its most important business sessions, the Association adopted an "Operators Certification Plan for Sewage Treatment Works Operators." Also, a proposed amendment changing the name of the Sewage Works Section to the Sewages and Industrial Wastes Section was passed without debate.

Of special interest to those in the sewage and industrial waste field were the following papers:

"Delaware's Radiological Program," "Certification of Plant Operators," "Closed Circuit Television for Sewer Inspection," "Effects of Detergents on Sewage Treatment," "Sewerage Services in Land Development," "Treatment of Food Processing Wastes," and "Service Problems in the Regulation of Water and Sewage Utilities."

Officers elected for the year 1959–60 were as follows:

President: Louis E. Otts, Jr., College Park, Md.
First Vice-President: C. Gordon Remsburg, Fort Meade, Md.
Second Vice-President: A. Joel Kaplovsky, Dover, Del.
Secretary-Treasurer: William A. Bingley, Baltimore, Md.

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(Continued through page 458a)

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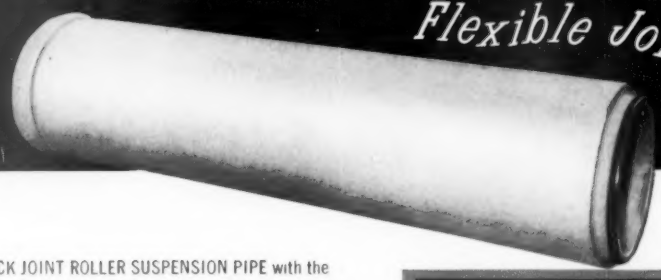

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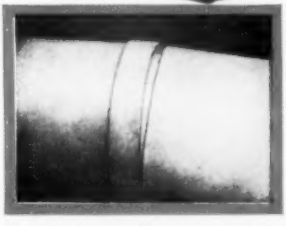

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